INRETS

Noise & Man '93

Noise as a Public Health Problem

Proceedings of the 6th International Congress

Nice, France
5-9 Juillet 1993

Volume 3

Actes INRETS N° 34 ter

Michel Vallet, editor

INSTITUT NATIONAL DE RECHERCHE SUR LES TRANSPORTS ET LEUR SECURITE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	5-9 Jul 93	Final Report 5-9 Jul 93

4. TITLE AND SUBTITLE
Sixth International Congress on
Noise as a Public Health Problem

5. FUNDING NUMBERS
CSP-93-1009

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Institute National de Recherche sur les Transports et
leur Securite
109 Ave Salvador Allende - Case 24
069675 Bron Cedex
France

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Sponsoring Agency:
European Office of Aerospace Research
& Development
PSC 802 Box 14
FPO AE 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release. Distribution unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT (*Maximum 200 words*)

This volume is the last of a series of 3 volumes, intended to give information on the 6th International Congress on Noise as a Public Health Problem, which took place in Nice, France from July 5 to 9 1993.
Volume 3 is composed of the texts of the conference invited and the invited papers, as well as the personalities' addresses. The abstracts of the 9 sessions in French and English are also integrated in this volume.

14. SUBJECT TERMS

15. NUMBER OF PAGES
608

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED

Noise & Man '93

Nice, France

Noise as a Public Health Problem

Volume 3

. official speeches
. key notes
. invited papers
. workshops
. summaries of each team

Michel Vallet, editor

Actes INRETS N° 34 ter

INSTITUT NATIONAL DE RECHERCHE SUR LES TRANSPORTS ET LEUR SÉCURITÉ

ISBN 2-85782-378 9
ISSN 0769-0266

Les commandes doivent être adressées (*orders should be made to*)
l'INRETS
Service Publications
2, Avenue du Général Malleret Joinville
94114 Arcueil Cedex
France

et être accompagnées d'un chèque bancaire ou postal de 500 FF (*with a cheque of 500 FF to*)
à l'ordre de l'Agent Comptable de l'INRETS

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PREFACE

Ce volume est le dernier de la série de trois ouvrages destinés à rendre compte du 6ème Congrès International sur le bruit comme problème de santé publique qui s'est tenu à Nice du 5 au 9 juillet 1993.

Le volume 1 publié en juillet 1993 comprend les résumés des 4 conférences principales, des 51 communications invitées sur les différents effets du bruit sur l'homme. On trouve aussi les considérations de la Commission des Communautés Européennes (DG XI) et de l'Organisation Mondiale de la Santé en matière de bruit, ainsi que 10 résumés des communications aux ateliers spéciaux sur le contrôle des dommages à l'oreille et sur le sommeil.

Le volume 2 intègre plus de 160 communications présentées par les participants.

Le volume 3 est composé des textes des conférences et des communications invitées, ainsi que des interventions des personnalités. Les résumés en anglais et en français de chacune des 9 sessions sont aussi intégrés à ce volume.

Pour retrouver le texte d'un auteur il convient de se réferer à la table la plus complète que l'on trouvera au volume 3.

L'ensemble des actes est publié grâce à l'aide des organismes cités dans les pages précédentes et je remercie tous ceux qui ont décidé ces aides.

Je remercie aussi mes collègues Patricia Champelovier, Jacques Lambert et Michel Maurin pour leur aide à la publication de ces actes et plus particulièrement Nicole Teillac et Isabelle Vernet pour la préparation des manuscrits.

Les traductions françaises ont été assurées par Mesdames A. Debonnet, B. Quetglas du CIDB et N. Teillac de l'INRETS.

Michel Vallet
Directeur de Recherche

FOREWORD

This volume is the last of a series of 3 volumes, intended to give information on the 6th International Congress on Noise as a Public Health Problem, which took place in Nice, France from July 5 to 9 1993.

Volume 1, published in July 93, includes the abstracts of the 4 main conferences, of 51 invited papers on the various effects of noise on human beeing. We can also find the reflections of the European Community Commission (DG XI) and the World Health Organization concerning noise, as well as 10 abstracts of the special workshop papers on control of the damage to the ear and on sleep.

Volume 2 is made up of 160 papers presented by the participants during the Conference.

Volume 3 is composed of the texts of the conference invited and the invited papers, as well as the personalities' addresses. The abstracts of the 9 sessions in French and English are also integrated in this volume.

These proceedings are published thanks to the help of the institutions quoted in the previous pages and I thank everybody who decided these aids.

I also thank my colleagues Patricia Champelovier, Jacques Lambert and Michel Maurin, for their help to the publishing of this proccedings and especially Nicole Teillac and Isabelle Vernet for the getting this manuscript ready.

French translations have been provided by Mrs A. Debonnet, B. Quetglas from the CIDB and N. Teillac from INRETS.

Michel Vallet
Director of Research

L'INRETS, Institut National de Recherche sur les Transports et leur Sécurité, créé en 1985 par la réunion de deux organismes, est placé sous la tutelle des Ministères de la Recherche et des Transports.

Sa mission est de :

. proposer des projets, conduire et évaluer la recherche et le développement sur des questions techniques, sociales et économiques dans le but d'améliorer les systèmes de transport et de trafic,
. diffuser et valoriser des résultats de recherche dans le domaine des transports,
. former des chercheurs spécialisés sur les transports en France et à l'étranger.

Les chercheurs travaillent en équipes multidisciplinaires sur des projets de recherche à la fois appliquée et fondamentale qui impliquent des collaborations avec les administrations ministérielles, l'industrie privée et les universités.

Directeur Général : Georges Dobias
Directeur Délégué Rhône-Alpes : Jean-Pierre Médevielle
Directeur du Laboratoire Energie Nuisances : Jean Delsey

INRETS, French National Institute for Transport and Safety Research, created in 1985 from two former institutes, is administered by the Ministry of Re·earch and the Ministry of Transport.

Its mission is to :

. plan, conduct and evaluate research and development on technical, social and economic issues to improve transportation and traffic systems,
. disseminate results of research on transportation issues,
. train transportation researchers in France and abroad.

The researchers work in multidisciplinary teams on both, applied and basic research projects, which involve collaboration with state agencies, private industry and universities.

Director General : Georges Dobias
Rhône-Alpes Regional Manager : Jean-Pierre Médevielle
Laboratory consumption and harmful effects' Manager : Jean Delsey

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NOISE RESEARCH AS A PROBLEM OF PUBLIC HEALTH

VALLET Michel
INRETS-LEN 109, Avenue Salvador Allende - 69500 BRON, France

The goal of noise research is to extend knowledge about auditory and non auditory phenomena and to influence noise abatement policies both in the context of public health, for example in the workplace or as a factor in the quality of life which also leads to the consideration of effects on health in the wider sense as defined by the World Health Organisation.

The on-going research undertaken for over 20 years has been able to provide the Civil Service with scientific data enabling decisions to be taken and the preparation of regulations.

This research effort has also ensured that Public Authorities are kept constantly aware of the exposure of people to noise. Noise is continually increasing despite noise abatement policies adopted by many nations including, of course, members of the OECD. It is probably true that regulations do not go far enough to protect the environment, that they are not always applied to their fullest extent - particularly in the workplace - and that the conclusions of scientists as to the most suitable noise thresholds may appear more theoretical than practical and do not often consider the costs involved. One result of this unambitious approach is that in Europe noise is becoming a major preoccupation of people in general. Noise continues to have a major impact on auditory and nervous systems and we are observing the appearance of specific forms of stress and psychosomatic disorders.

Workplace surveys carried out in France in 1978, 1984 and again in 1991 show that the main grievances are unchanged - standing for long periods, breathing dusts and being subjected to very loud and very high pitched noises. In industry noise ranks second and concerns one worker in two - an increase vs. 1984.

However, the situation in schools was much improved by soundproofed facades and by reducing acoustic reverberation in classrooms and canteens.

At the end of 1992 the French Parliament passed a law on noise abatement with an ambitious but rather realistic objective which was to limit domestic exposure to noise to a Leq of 60 dB (A). This major decision by the Ministry for the Environment was backed by research which showed that the previous threshold of 65 dB (A), which only applied to roads, was no low enough and did not satisfy the population.

Findings showed that although the 65 dB (A) threshold eliminated most health risks it did not meet the WHO definition of well-being. The Swiss threshold goal of 55 dB (A) clearly aims to ensure comfort.

Quite obviously a single threshold value is not realistic for all places and all periods throughout the day. Very low daytime thresholds in urban sites are not realistic. Current research is examining ways in which to differentiate noise thresholds better adapted to the sites to be protected. In France work is proceeding for a proposal for a specific evening and night time acoustic index.

The economic aspects of the effects of noise on health were not hardly discussed in Nice whereas standards and regulations led to a specific session. Some countries (Italy, for example) have recently introduced new laws concerning ambient noise. Other countries have strengthened regulations for workplace noise and it is clear that more stringent regulations will be introduced. Noise is a factor in our civilisation and has already become a systematic preoccupation of employers, ergonomists and home and airport builders ; technical possibilities enable significant reductions in perceived noise but noise sources are becoming more numerous which means that the situation is not really improving.

LA RECHERCHE SUR LE BRUIT COMME PROBLÈME DE SANTÉ PUBLIQUE

Michel Vallet - INRETS

Ce congrès a été organisé par l'Institut National de Recherche sur les Transports et leur Sécurité (INRETS, Lyon-Bron) en collaboration avec la Commission Internationale sur les Effets Biologiques du Bruit (ICBEN) et le soutien de plusieurs ministères français et d'organisations internationales. Le but de ce congrès est de présenter de nouveaux résultats, d'encourager la coopération internationale dans la recherche sur les effets biologiques du bruit, d'échanger et de divulguer les informations et les idées, de promouvoir les relations entre les chercheurs scientifiques, les agences gouvernementales et les responsables chargés de la protection de la santé et du bien-être.

Près de 400 participants ont assisté à cette manifestation: médecins, ingénieurs, psychologues, sociologues, décideurs locaux. Tous les pays du monde y étaient représentés : Brésil, Norvège, Grande Bretagne, Australie, USA, Espagne, Pologne, Autriche, Canada, Chili, Japon, Portugal, Italie, Danemark, Allemagne, France... 50 conférences ont été présentées, accompagnées de 160 communications affichées et de deux ateliers s'articulant autour de deux axes: les bruits et leurs répercussion psychosomatiques.

La recherche en matière de bruit a pour finalité de faire avancer la connaissance sur les phénomènes auditifs et non auditifs et d'orienter les politiques de lutte contre le bruit, que celui-ci soit considéré comme un problème de santé publique, c'est bien le cas au travail, ou comme un élément du cadre et de la qualité de la vie, ce qui revient à considérer l'impact sur la santé au sens large défini par l'Organisation Mondiale de la Santé.

La continuité de la recherche depuis plus de 20 ans a permis de fournir à l'Administration des éléments scientifiques pour la prise de décisions et de réglementations.

Le rôle de la recherche dans les choix politiques

Elle a contribué à maintenir l'attention des pouvoirs publics sur le problème de l'exposition des habitants au bruit, exposition dont l'ampleur continue de croître régulièrement, malgré les politiques de lutte contre le bruit adoptées dans de nombreux pays dont ceux de l'OCDE. Il est vraisemblable que les réglementations manquent d'ambition en matière d'environnement, qu'elles sont mal appliquées, notamment au travail, et que les conclusions des chercheurs en terme de seuil de bruit apparaissent à certains utopiques, surtout au regard des contraintes économiques. Un résultat de ce manque d'ambition est que le bruit, en Europe, focalise de plus en plus les préoccupations de la population. Le bruit continue, chez un nombre croissant de personnes, de solliciter le système auditif et le système nerveux, favorisant l'apparition d'un stress spécifique et de maladies psychosomatiques.

Au travail, rester longtemps debout, respirer des poussières, subir des bruits très forts ou très aigus restent en 1991, comme lors des enquêtes de 1978 et 1984 réalisées en France, les aspects les plus pénibles. Dans l'industrie, le bruit vient au 2ème rang et concerne un ouvrier sur deux, ce qui est une augmentation par rapport à 1984. Cependant la situation dans les écoles a été très améliorée par les isolations de façade et par le traitement de la réverbération acoustique dans les salles de cours et les restaurants scolaires.

En France, à la fin de l'année 1992, le Parlement a voté une loi sur la protection contre le bruit avec un objectif ambitieux, mais non irréaliste, de limiter l'exposition des logements à un maximum de 60 dB (A) (en niveau énergétique équivalent de jour). Les travaux de recherche ont aidé à la prise de cette décision importante du Ministère de l'Environnement, en soulignant dans les résultats expérimentaux, que le seuil précédent de 65 dB (A) et appliqué seulement aux routes nationales, n'était pas assez bas, et qu'une certaine insatisfaction demeurait parmi la population.

Si ce seuil de 65 dB (A) évite la plupart des atteintes à la santé, il ne procure pas encore le bien être évoqué dans la définition de la santé par l'O.M.S. La Suisse en proposant 55 dB (A) comme seuil de planification vise clairement un seuil de confort. On peut considérer qu'une seule valeur seuil n'est pas réaliste pour tous les lieux et toutes les périodes de la journée. De même des seuils trop bas pour la journée, en site urbain, ne sont pas réalistes. L'orientation actuelle des recherches consiste à examiner l'intérêt de seuils de bruit différenciés et adaptés aux sites à protéger. Ainsi, en France, on travaille sur une proposition d'indice acoustique spécifique de soirée et de nuit.

Vers des réglementations plus sévères

Les aspects économiques des effets du bruit sur la santé ont été peu présentés à Nice, où au contraire les normes et les réglementations ont donné lieu à une session particulière. Certains pays ont vu naître de nouvelles lois contre le bruit de l'environnement (Italie par exemple). Les règlements sont renforcés dans d'autres pays ou pour le bruit au travail. Il est clair que l'on va vers des réglementations plus sévères. Le bruit est un élément de notre civilisation, il est entré dans les préoccupations systématiques des employeurs et des ergonomes, des constructeurs de bâtiments ou d'infrastructures de transport ; les procédés techniques permettent des réductions sensibles des doses reçues mais les sources de bruit se multiplient, ce qui fait que la situation ne s'améliore pas vraiment.

INTRODUCTORY REMARKS

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On behalf of the International Commission on Biological Effects of Noise let me welcome you on this first day of the 6th International Congress on Noise as a Public Health Problem. I would like to welcome our honored and distinguished guests and to welcome all of you the participants to this congress. Your presence here today and for the few days to come shows how important this meeting is.

The Commission wishes to thank specially those who have made this congress possible. Among them, the acoustical societies, the French Government and public research organizations, several organizations from different european countries as well as from the U.S.A. and Canada, the Commission of the European Communities and the World Health Organization and, of course, INRETS, Michel Vallet and his co-workers.

The program for this congress is organized around the nine international teams which constitute the Commission and define its interests. Each of these nine groups is composed of about twelve scientists who are experts in the field covered by the team. No more than two members in each team have the same nationality and this rule makes these groups truly international.

The main purpose of this meeting is to bring together scientists, industrial and governmental working people, as well as individuals and representatives of organizations and associations, to exchange their knowledge and interrogations and, in a word, to communicate.

Today many people, in and outside the cities, are exposed to the noise that transportation systems, factories and outdoor activities produce day and night. The adverse health effects of noise on man are still difficult to determine because of the interaction of noise with other environmental factors and because of those factors, identified or not, which tend to make people react in a different manner from each other. But after all, each of us is concerned with the protection against noise as we all contribute to its production.

We know that research cannot solve all the problems we are going to discuss in the next few days. But we know also that there is no better place to have these discussions between researchers and those who have to take and to apply the decisions. In order to reach this goal we need to obtain a critical and constructive cooperation of all the present bodies. An international meeting like this one is necessary to increase communication and exchange our experience. We should all profit from the knowledge that you bring with you and pass around. I wish this congress success in making this important goal possible.

REMARQUES D'INTRODUCTION

MUZET Alain
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Au nom de la Commission Internationale sur les Effets Biologiques du Bruit (ICBEN), c'est un plaisir de vous accueillir ce premier jour du 6ème Congrès International sur le Bruit comme Problème de Santé Publique. J'aimerais accueillir nos honorés et éminents invités ainsi que tous les participants à ce congrès. Votre présence ici ce jour et pour les jours prochains montre l'importance de cette réunion.

La Commission désire remercier en particulier ceux qui ont rendu ce congrès possible. Parmi eux, les sociétés d'acoustique, le Gouvernement français et les organismes de recherche publics, plusieurs organismes des différents pays européens ainsi que des Etats-Unis d'Amérique et du Canada, la Commission des Communautés Européennes et l'Organisation Mondiale de la Santé, et bien entendu, l'INRETS, Michel Vallet et ses assistants.

Le programme de ce congrès est organisé autour de neuf équipes internationales qui constituent la Commission et définissent ses intérêts. Chacun de ces neuf groupes est composé d'à peu près dix scientifiques qui sont experts dans le domaine couvert par l'équipe. Pas plus de deux membres dans chaque équipe ont la même nationalité et cette règle rend ces groupes vraiment internationaux.

Le but principal de cette conférence est de réunir les scientifiques, des personnes travaillant dans l'industrie et au gouvernement, ainsi que des particuliers et des représentants d'organisations et d'associations, pour échanger leurs connaissances et leurs questions et, en un mot, pour communiquer.

Aujourd'hui plusieurs personnes, dans et à l'extérieur des villes, sont exposées au bruit produit jour et nuit par les systèmes de transport, les usines et les activités extérieures. Les effets défavorables du bruit sur la santé de l'homme sont toujours difficiles à déterminer à cause de l'interaction du bruit avec les autres facteurs environnementaux et à cause de ces facteurs, identifiés ou non, qui ont tendance à faire réagir les gens différemment les uns des autres. Mais après tout, chacun de nous est concerné par la prévention du bruit car nous contribuons tous à sa production.

Nous savons que la recherche ne peut pas résoudre tous les problèmes dont nous allons discuter ces prochains jours. Mais nous savons aussi qu'il n'y a pas de meilleur lieu par avoir ces discussions entre chercheurs et ceux qui ont à prendre et à appliquer les décisions. En vue d'arriver à ce but nous avons besoin d'avoir une coopération critique et constructive pour toutes les parties présentes. Une réunion internationale telle que celle-ci est nécessaire pour augmenter la communication et échanger notre expérience. Nous pourrions tous profiter du savoir que vous amenez avec vous et que vous ferez passer. Je souhaite que ce congrès réussisse à atteindre ce but important.

LES EFFORTS DU MINISTÈRE DE L'ENVIRONNEMENT EN MATIÈRE DE BRUIT

Pierre SCHMELTZ
représentant du Ministre de l'Environnement, France

Le Ministère de l'Environnement, depuis 1971, c'est à dire depuis sa création a eu dès de départ le souci de lancer des études et des recherches dans le domaine du bruit. Pourquoi ? Parce-que je crois que dans tous les autres pays ça doit être la même chose, on a toujours eu tendance à minimiser les effets du bruit sur l'homme en disant pendant longtemps que les gens qui se plaignaient du bruit étaient des acariâtres, des malades, des vieux, des mauvais voisins. Et donc nous pensons au Ministère de l'Environnement, et avec vous bien entendu, que les effets du bruit sont extrêmement pénibles pour l'homme dans la mesure où en dehors des effets auditifs, des effets directs sur l'oreille qui sont bien connus dans le milieu du travail, les effets extra-auditifs, ceux qui nous intéressent aujourd'hui au premier chef, sont des effets qui apparaissent à long terme. Donc ils nécessitent un gros effort de recherche et de mise en évidence des causes et des effets. Le gros problème de la recherche est de convaincre les décideurs politiques. Et cela n'est pas facile, parce qu'un homme politique ne veut décider une politique que s'il est sûr, que s'il croit aux raisons de faire quelque chose. C'était depuis longtemps un acte du Ministère de l'Environnement. Convaincre les décideurs, c'est leur montrer effectivement les conséquences dommageables pour l'individu, pour la société, pour donc montrer qu'il y a des dommages qui sont extrêmement importants, même si on ne sait pas les quantifier, ou si on sait mal les quantifier en tout cas. Depuis le début des années 80, ce qui est important en France, c'est que la politique qui a été menée par le Ministère de l'Environnement débouche justement directement des constats fait par la recherche. Je citerais deux exemples : le premier sur des études qui ont été menées dès le début des années 75 par des équipes, notamment j'en profite pour citer mon ami Michel Vallet, qui a été à l'origine de grandes études qui ont été menées en France sur le thème du bruit et du sommeil qui ont montré effectivement l'influence et l'importance des atteintes du bruit, notamment des transports routiers terrestres, sur le sommeil des gens et que quelles que soient les accoutumances, quelles que soient la façon dont les riverains pouvaient s'en accommoder apparemment, il y avait des effets qui étaient finalement permanents sinon irréversibles. Cela est une première conséquence pour montrer que la recherche est importante. Donc dès le début des années 80, le Ministère de l'Environnement a mis en oeuvre une politique en matière de protection des riverains des infrastructures de transport. Cette politique s'est concrétisée de deux façons. La définition de niveau sonore pour les infrastructure neuves, donc mise en oeuvre de protection lors de la création de voies nouvelles et parallèlement, ce qui était important, une réflexion sur la mise en oeuvre d'une politique de rattrapage, parce qu'on nous dit toujours quand on prend de nouvelles lois ou de nouveaux textes c'est très bien pour les nouvelles choses que l'on va faire mais les gens qui vivent dans des situations anormalement bruyantes, qu'est-ce qu'ils deviennent ? Qu'est-ce que l'on fait pour eux ? On a, parallèlement à ça, mis en oeuvre des

réflexions là-dessus. Un autre thème extrêmement important mis en oeuvre au début des années 80, a été une politique en direction de l'enfance. L'enfance à plusieurs degrés : l'enfance à l'école, beaucoup d'études ont montré l'importance de l'acoustique des locaux scolaires par exemple. Dans l'acquisition des connaissances, c'est banal de dire qu'une salle mal insonorisée, qui a une mauvaise acoustique, ne permet pas à des enfants d'entendre bien le message de l'enseignant et donc d'avoir des chances de bien mémoriser le message. Aujourd'hui on lance également une grande politique en milieu scolaire. Mais il y a en direction de l'enfance d'autres effets qui apparaissent je crois dans tous les pays, ce sont les effets dûs à la pratique de la musique à un haut niveau. Cela commence à inquiéter beaucoup le Ministère de l'Environnement, que ce soit avec les baladeurs d'un côté, je vous rappelle qu'avec un baladeur on peut avoir plus de 100 décibels dans les oreilles, jusqu'à 110 décibels, et que la pratique de la musique à un haut niveau dans les discothèques ou les pistes de danse vous avez des niveaux sonores de l'ordre de 110 à 115 décibels. Beaucoup de rapport d'études et notamment des rapports sur les jeunes avant qu'ils ne rentrent à l'Armée, c'est à dire que les militaires font des études avant l'incorporation, montrent que un jeune sur deux en France a des pertes d'acuité auditive de l'ordre de 15 à 20 décibels, ce qui est quand même considérable dans les populations des jeunes de 18-20 ans. Pour le Ministère de l'Environnement, ce qui est extrêmement important est de protéger les riverains des infrastructures des transports d'un côté, protéger les jeunes soit à l'école soit dans leurs loisirs. Je crois que ce sont les deux axes. Il y en a beaucoup d'autres, je ne vais pas les développer mais actuellement ce sont deux axes qui nous paraissent fondamentaux. Dans ce cadre là, le Ministère de l'Environnement et le Gouvernement français de façon générale préparent ce qu'on appelle en France un plan de relance de l'économie, vous savez que nos économies occidentales souffrent actuellement de dépression et il a paru intéressant au gouvernement français de lancer un grand programme de soutien au bâtiment et aux travaux publics. L'originalité de ce programme est que pour la première fois, en France en tout cas, va comporter un volet environnement extrêmement important et ce volet environnement va être essentiellement accroché à la lutte contre le bruit. Le ministère travaille à fond sur le plan de relance du bâtiment et des travaux publics dans sa partie acoustique. Ce plan de relance va se focaliser pour le bruit dans deux domaines : un grand programme d'amélioration acoustique dans les écoles et un grand programme de rattrapage le long des voies routières pour protéger les riverains notamment des banlieues périurbaines comme on en connaît dans tous nos pays. La France, en 18 mois, va consacrer plus de 300 millions de Francs au niveau de l'État, c'est à dire qu'il va y avoir compte tenu des financements annexes des collectivités locales, un programme de l'ordre d'un milliard de Francs en 18 mois consacré à la lutte contre le bruit, ce qui est un effort sans précédent en France. Je voulais dire, simplement pour vous montrer ces deux aspects que la recherche est fondamentale si l'on veut que les décideurs politiques prennent en compte la lutte contre le bruit et décident de programmes de travaux. Le souci, le service du bruit du Ministère de l'Environnement, quand on veut convaincre les hommes politiques, il faut absolument leur montrer les relations qui existent, quels sont les dommages qui sont provoqués par quelque chose pour qu'ils acceptent d'agir. Or la difficulté que nous avons dans le bruit est partout, c'est de mettre en relation le coût des dommages et on ne sait pas bien les chiffrer. Je crois que les axes à donner, sont ceux relatifs à la notion de coût social du bruit. Tout le monde sait partout que le bruit coûte très cher à la société, on le voit quand on regarde les Sécurités Sociales ou les budgets des

Ministères de la Santé. Ceci dit on souffre d'une chose, on sait très mal relier les dommages à des coûts. C'est un gros handicap du bruit alors que dans les autres politiques de pollution des eaux, de pollution de l'air etc., les dommages se quantifient, se chiffrent et ce n'est pas trop difficile de mettre en oeuvre des politiques. Dans le domaine du bruit c'est presque un pari de Pascal si je peux dire. Je crois que c'est un axe extrêmement important de réfléchir, d'essayer de travailler sur ce coût social. Deuxième thème de recherche du Ministère de l'Environnement que je souhaiterais qui puisse être développé par la recherche, c'est une recherche sur les descripteurs, les indicateurs. Je suis frappé quand on essaie de comparer les politiques de tous les pays, de voir que nous n'utilisons pas les mêmes indicateurs pour décrire les dommages. Je pense qu'un effort pourrait être fait pour que nous utilisions partout les mêmes indicateurs, ce serait extrêmement important parce-que au jour d'aujourd'hui chaque pays a tendance à copier, dans le bon sens du terme, à regarder ce que font les autres pays et à utiliser les acquis des recherches des autres pour faire sa propre philosophie et mener ses propres études. Je crois que l'on gagnerait beaucoup de temps si nous utilisions le même langage, les mêmes indicateurs, etc. C'est un souhait que je formule.

EUROPEAN COMMUNITIES NOISE POLICY IN THE LIGHT OF THE 5TH ENVIRONMENTAL ACTION PROGRAMME

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On behalf of the Commission of the European Communities and on my own behalf I was happy to accept the invitation of the organisation of the 6th International Congress on Noise as a Public Health Problem. I believe that the importance of this congress lies in its concentration on just this topic : Man and Noise. In the different sections all main effects of noise on man and his well-being are included, inter alia, noise and communication, non-auditory physiological effects induced by noise, noise and performance and behaviour, sleep disturbance by noise and noise and hearing loss.

In this conference of outstanding physicians and acousticians from all over the world you do not need me to remind you of these various significant impacts of noise. The fundamental issue which I am sure you would wish me to address is : how is the European Community going to promote policies to reduce this impact ?

The present noise policy of the European Communities has been primarily based on directives which deal with sound emissions of cars, trucks, aircraft, special types of construction plant and equipment, lawnmowers, etc. Valuable as they are it must however be admitted that these directives have been motivated only in past by environmental concerns, their essential role being in the harmonization of products norms required for the achievement of the Single Market. The Communities recently approved the 5th Environmental Action Programme, which was adopted by the Council on 1st February 1993, it is foreseen that the Community will be seeking to further contribute to noise abatement by reduction in permissible noise emission levels.

This 5th Environmental Action Programme has also broken new ground in the area of Community noise policy by introducing for the first time the question of Community set noise quality objectives, setting out the following targets up to the year 2000 in respect to Leq in dB(A) at night-time :

- exposure of the population to noise levels in excess of 65 should be phased out : at no point in time a level of 85 should be exceeded.
- proportion of population at present exposed to levels between 55-65 should not suffer any increase.
- proportion of population at present exposed to levels less than 55 should not suffer any increase above that level.

Although the setting of this initial set of objectives is important, they obviously do not represent a comprehensive noise criteria policy. If the Community is to develop such policy, we must build on these initial targets to the full range of noise situations and also review, on the basis of further considerations and research, the initial targets proposed.

In developing this work the Commission needs close cooperation with specialists, institutes and international organizations. Of particular value would be collaboration with the WHO who we know are very active in this field. At present the Commission is exploring such collaboration on the lines of our existing collaboration agreement on air quality issues.

The establishment of other objectives in the area of noise reduction will, I fell, be of fundamental importance in driving forward noise abatement policies throughout the Community. This is not to suggest that the Commission is seeking to extend its competence and role in the issue, but sees these criteria as aiding the establishment of objective targets for product noise limits by the Community as well as targets for the more local actions which are rightly within the competence of national and local governments.

The potential role of the European Environment Agency must not be underestimated. The establishment of monitoring programmes to check on the achievement of targets and the provision of good information to general public should not be underestimated as a force to increase the priority given at all levels to the implementation of meaningful action to reduce noise.

I wish the 6th International Congress on Noise as a Public Health Problem great success with clear-cut results, capable of being understood both by the general public and by decision-makers.

La politique de lutte contre le bruit dans les Communautés Européennes à la lumière du cinquième programme d'action sur l'environnement

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J'ai été heureux d'accepter l'invitation du comité d'organisation du 6ème Congrès sur le Bruit comme Problème de Santé Publique, au nom de la Commission des Communautés Européennes et en mon propre nom. Je crois que l'importance de ce congrès se situe dans sa concentration sur ce seul sujet : l'homme et le bruit. Dans les différentes parties tous les principaux effets du bruit sur l'homme et son bien être sont compris, parmi d'autres, le bruit et la communication, les effets physiologiques non auditifs, impact du bruit sur la performance et le comportement, la gêne du sommeil et les pertes auditives dues au bruit.

Dans cette conférence de remarquables physiciens et acousticiens du monde entier vous n'avez pas besoin que je vous rappelle ces différents impacts importants du bruit. Je suis sûr que la question fondamentale dont vous aimeriez que je parle est : comment la Communauté Européenne va-t-elle promouvoir les politiques de réduction de cet impact ?

La politique actuelle des Communautés Européennes sur le bruit a tout d'abord été fondée sur les directives qui traitent des émissions de bruit de véhicules, de camions, d'avions, de types particuliers de bâtiments de construction et d'équipement, de tondeuses à gazon, etc. On doit toutefois admettre que ces directives précieuses n'ont été dernièrement motivées que par des intérêts environnementaux, leur rôle essentiel étant l'harmonisation des normes exigées pour exécuter le marché unique. Les Communautés ont récemment approuvé le 5ème Programme d'Action sur l'Environnement, qui fut adopté par le Conseil le 1er février 1993, il est prévu que la Communauté cherchera à contribuer davatange à la diminution du bruit par la réduction des niveaux acceptables d'émission de bruit.

Ce cinquième Programme d'Action sur l'Environnement a aussi jeté les bases du domaine de la réglementation du bruit de la Communauté en introduisant pour la première fois la question d'une série d'objectifs de qualité du bruit de la Communauté, en cherchant les cibles suivantes au-delà des années 2000 par rapport au Leq en dB(A) pendant la nuit :

- l'exposition de la population à des niveaux de bruits dépassants 65 devrait être supprimée progressivement : à aucun moment le niveau de 85 de crête ne devrait être dépassé.
- la proportion de population actuellement exposée à des niveaux entre 55-65 ne devrait pas subir d'augmentation.
- la proportion de population actuellement exposée aux niveaux inférieurs à 55 ne devrait pas subir d'augmentation au dessus de ce niveau.

Bien que la mise en place de cette série initiale d'objectifs est importante, ils ne représentent apparemment pas une politique totale de critères du bruit. Si la Communauté développe une telle politique, nous devons ajouter à ces cibles initiales une gamme complète de situations au bruit et également étudier, sur la base de considérations futures et la recherche, les cibles initiales prop[illegible]ées.

En développant ce travail la Commission a besoin d'une coopération étroite avec les spécialistes, les instituts et organisations internationales. La collaboration de l'O.M.S. qui nous le savons est très active dans ce domaine serait d'une grande valeur. Actuellement la Commission examine une telle collaboration dans la même lignée que notre collaboration actuelle sur les questions de qualité de l'air.

La création d'autres objectifs dans le domaine de la réduction du bruit sera, je crois, d'une importance fondamentale pour faire avancer les politiques de réduction du bruit parmi la Communauté. Il ne s'agit pas que la Commission cherche à étendre sa compétence et son rôle en cette question, mais qu'elle voit ces critères comme une aide pour la création de cibles objectives pour les limites d'émission de bruit par la Communauté aussi bien que des cibles pour des actions plus locales qui sont bien dans la compétence de gouvernements nationaux et locaux.

Le rôle potentiel de l'Agence Européenne pour l'Environnement ne devrait pas être sous-estimé. La création de programmes de contrôle pour vérifier l'accomplissement de ces cibles et la fourniture de bonnes informations au public ne devraient pas être sous-estimées comme une contrainte à augmenter la priorité donnée à tous les niveaux pour l'accomplissement d'actions significatives pour diminuer le bruit.

Je souhaite beaucoup de succès au 6ème Congrès International sur le Bruit comme Problème de Santé Publique par des résultats clairs, capables d'être compris par le public et ceux qui prennent les décisions.

COMMUNITY NOISE

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Community noise covers all aspects of noise with the exception of occupational noise. The Regional Office for Europe of the World Health Organization (WHO), in collaboration with its Headquarters, has updated their recommendations in this field in the light of the most recent acquired technological developments

The final document is not yet published, but I have pleasure in presenting the last provisional draft before its publication. Should you wish to make any comments you are most welcome. A note inside the document indicates where to address them.

This document has been written on the following basis:

- What are the various effects of noise on health ? What sound levels can be considered as acceptable in newly planned activities ?

- The authors have then proposed guidelines related to various living environments.

- The guidelines document does not establish any recommendation regarding noise sources. This type of recommendation belongs to the regulatory field which is for state competence. Only organizations with a mandate to establish regulations can usefully propose such recommendations.

Compared to guidelines published in 1980 in the Environment Criteria Document, No. 12, the new values proposed show a slight overall decrease. However, a few new aspects related to noise such as Walkman are covered. A whole chapter is now devoted to further research needed.

It is clear that although not proposing guideline values WHO does not neglect recommendations related to:

- Noise protection measures

- Relevant transportation infrastructure to mitigate noise pollution.

- Institutional and regulatory tools necessary to implement a sound and efficient noise abatement policy.

All these aspects are covered through other projects of the Regional Office.

LE BRUIT D'AMBIANCE

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Le bruit d'ambiance couvre tous les aspects du bruit à l'exclusion du bruit en milieu de travail. Le Bureau régional pour l'Europe de l'Organisation mondiale de la Santé (OMS), en association avec le siège de l'OMS, ont tenu à actualiser leurs recommandations dans ce domaine à la lumière des acquis techniques les plus récents.

Le document final n'est pas encore publié, mais j'ai le plaisir de présenter à l'occasion de ce Congrès la dernière version provisoire avant publication. Tous ceux d'entre vous qui souhaiteraient présenter des commentaires sont les bienvenus et une note à l'intérieur du document leur précise l'adresse où les faire parvenir.

Ce document est basé sur la logique suivante:

- Quels sont les différents effets du bruit sur la santé, en fonction de ces effets quels niveaux sonores peuvent être considérés comme acceptable en fonction des activités humaines envisagées ?

- Ces valeurs-guides étant proposés, les auteurs se sont attachés à définir des valeurs-guides en fonction de l'environnement dans lequel nous évoluons.

- Le recueil des valeurs-guides de l'OMS pour le bruit ne propose aucune recommandation pour les sources de bruit. En effet, il s'agit là du domaine réglementaire propre à chaque Etat et seule une organisation ayant pouvoir d'établir des règles s'imposant à tous ses membres pourrait faire oeuvre utile en ce domaine.

Par rapport aux valeurs-guides publiées en 1980 dans les critères d'hygiène de l'environnement, No. 12, sur le bruit il y a globalement une légère révision à la baisse. De plus certains aspects récents tels que le bruit des balladeurs sont couverts. Enfin, un chapitre relativement important est consacré aux axes de recherche recommandés.

Il est évident que le fait de ne pas proposer de valeurs-guides pour les émissions n'implique pas de la part de l'OMS qu'elle néglige toutes les recommandations relatives:

- aux mesures de protection contre le bruit,

- aux infrastructures appropriées de transport pour limiter les nuisances sonores

- aux aspects réglementaires et institutionels nécessaires à la mise en place d'une politique efficace contre le bruit.

Ces aspects sont couverts par d'autres projets du Bureau régional.

PSYCHOLOGICAL APPROACH TO NOISE RESEARCH FOR FUTURE NEEDS

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ABSTRACT

Noise is not a global problem but a typical environmental problem which causes sensory pollution. Paying attention to noise can help to cultivate an enlightened attitude towards environmental problems in general. To determine what effective countermeasures against noise are, we have to consider the following. (1) The relation between cost and benefits in preventing environmental pollution. The possibility of finding measures to reduce noise without adding to the consumption of energy and resources. (2) The importance of composite noise rating methods which precisely predict the effects of noise on man from physical measurements. These methods should take prominent frequency components, regular and irregular level-fluctuation and the directions of noise sources into consideration. (3) The importance of personal, social and cultural backgrounds for evaluating the effects of noise on man. (4) The need to establish theoretical models which take ecological values into account. For this, the coordination of basic and applied research is important.

1. INTRODUCTION [1]

Environmental pollution is a global problem and a major way of dealing with it is by saving energy and resources. Restrictions will result in much inconvenience and may even threaten things we take for granted as part of modern life. If we wish to maintain a comfortable life-style without causing the destruction of the environment, we have to develop new techniques for maintaining this standard of life, which are not based on consumption and which will contribute to the saving of energy and resources. It is clearly reasonable to propose this, but practical action will face many difficulties. One is that it is not easy to reach general agreement between nations about the way in which expenses will be shared. Another is that industrial companies which develop new technology for environmental protection after huge investment probably will not like to make it available without some financial return. Finally, developing countries which have many resources will wish to exploit them in order to achieve a higher standard of living. To protect our environment and improve conditions we must recognize that we have to share the burden of cost and effort and we must take a determined attitude towards environmental problems.

Noise is not a global problem. Sound energy is not accumulated, and the area which suffers from noise is limited to that around the noise source. However, the effect of noise on man is not unimportant, as those who suffer from it would readily agree. Many machines which make noise are commonly used in many countries and can be a cause of noise problems. Acoustics can contribute to reducing noise but, like solutions to other pollution problems, this cannot be achieved without expense. As with other types of pollution, we have to consider the relation between cost and benefits.

Noise is sensory pollution. Everyone can recognize its bad effects without using measuring instruments. By taking care, everyone can contribute to the prevention of the problem to some degree, and the effectiveness of technical countermeasures is easily perceived. In some respects noise is a typical environmental problem, but its causes and consequences, and its solution, are

more obvious to ordinary people. Paying attention to noise can help to cultivate an enlightened attitude towards environmental problems in general.

Countermeasures against noise which require great expenditure of energy and resources cannot be adopted even if they are very effective. For example, air-conditioner noise will decrease when the speed of the fan is reduced but this also reduces the efficiency of the air-conditioning. A better solution is possible, though it is more difficult to achieve: the noise can be reduced without lowering efficiency by designing fans of a more effective pattern. This is just one example from among many which shows how countermeasures against noise have to be considered in relation to energy and resources. To arrive at the most effective solutions, psychological factors must be taken into account.

From the psychophysical point of view, some physical features of sound are of special significance. More precise methods for predicting the effect of noise on man are being developed. One of them involves finding more precise noise indices based on the relation between physical parameters of sound and subjective response.

2. FREQUENCY CORRECTION

A-weighting is widely adopted in the measurement of noise and for regulations concerning noise. A-weighting is approximately the reversed function of the equal loudness contour of 40 phons. There are no theoretical reasons for general use of A-weighting.

Many methods for calculating loudness based on psychophysical models and experimental findings have been proposed. Among them are Stevens' method (LLs) and Zwicker's method (LLz), which have been adopted in ISO 532[2] for calculating the loudness level of broad-band steady state sounds. These methods have some theoretical foundation.

LLz is a kind of simulation of the basilar membrane of the inner ear. The procedure for calculating LLz is very complicated and its use in practical applications has not proved popular, even though a simplified model has been developed for engineering purposes. A computer program for calculating LLz has recently become available in Japan (Zwicker et al.[3]) which facilitates the adoption of LLz for practical applications.

There have been experiments by Namba and Kuwano[4] concerning the loudness of various kinds of non-steady state sounds in which the propriety of A-weighted sound pressure level (dBA), LLs and LLz were compared. LLs and LLz showed better correspondence with loudness than A weighted sound pressure level, although the difference was not great. In practical applications, simplicity is as important as accuracy and in this regard A-weighted sound pressure level has some advantages.

However, with sounds having prominent components in some frequency regions, LLz showed better correspondence with loudness than A-weighted sound pressure level. For example, as is shown in Fig.1,[5] in the case of broad band noise having strong pure tone components with amplitude modulation, LLz is a better index than dBA. A similar tendency was found in the case of broad band noise with frequency modulated pure tone components[6](Fig.2 :air-conditioner noise). These results provide a useful guide for the evaluation of noise from machines and for the design of machines where reduction of noise is an important consideration.

For the precise prediction of loudness, methods based on 1/1 or 1/3 octave band analysis are better than the method where one-channel measurement, such as A-weighed sound pressure level, is the basis. In the case of the former, there is the possibility of improving precision as basic research on the mechanism of hearing and the processing of the loudness of complex sounds progresses. The possible effects of loudness scaling, masking pattern, partial masking, recruitment in the low frequency region and critical bandwidth need to be considered more carefully. Fuller cooperation is desirable between those in the basic area of auditory research and those in applied fields.

3. EVALUATION OF NON-STEADY STATE SOUNDS

ISO 532 is only applicable to steady state sounds. In daily life situations, however, almost all sounds are various kinds of non-steady state sound, such as road traffic noise, aircraft noise, train noise, construction noise, music and speech. It is important to decide on a representative value for the overall level-fluctuations. The Japanese Industrial Standard, JIS Z8731[7], and ISO 2204-1973 (E)[8] define several kinds of level-fluctuation.

JIS Z8731 recommends Leq (equivalent continuous A-weighted sound pressure level in decibels) as well as Lx (percentile levels) for the measurement of fluctuating noise. Namba and Kuwano et al.[9,10] have investigated the advantages of Leq as a measure of the loudness of various kinds of non-steady state sound in comparison with Lx. As is shown in Fig.3, Leq showed good correspondence with loudness. In some stimulus conditions where the value of Lx is constant and the distributions of level-fluctuation are varied, there is no relation between Lx and loudness as shown in Fig.4. Nevertheless, in Japan, Lx is still used for the regulation of environmental noise for practical reasons, but I am convinced that Leq will replace Lx in the near future.

For the evaluation of impulsive sounds, Kuwano and Namba[11] have confirmed

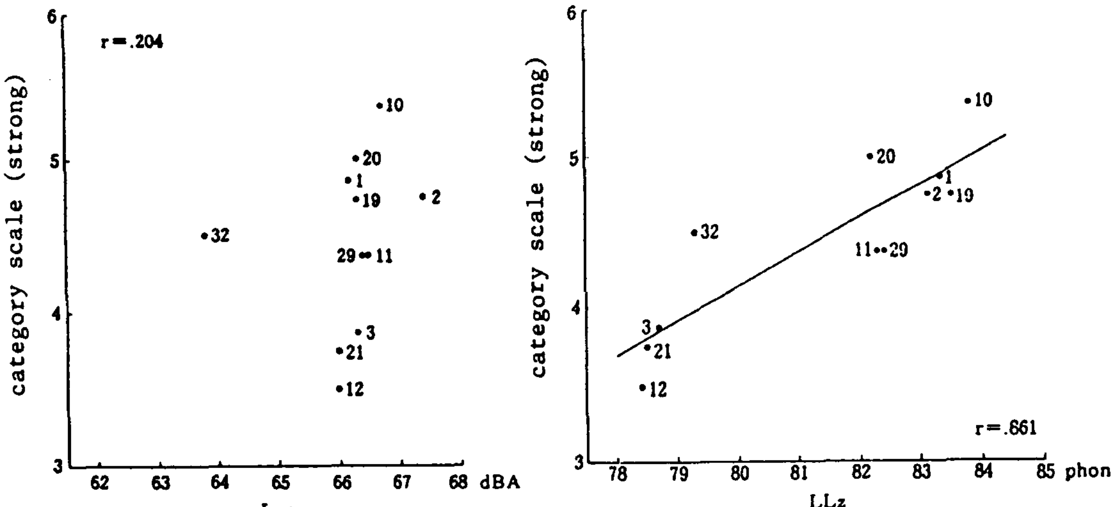


Fig.1

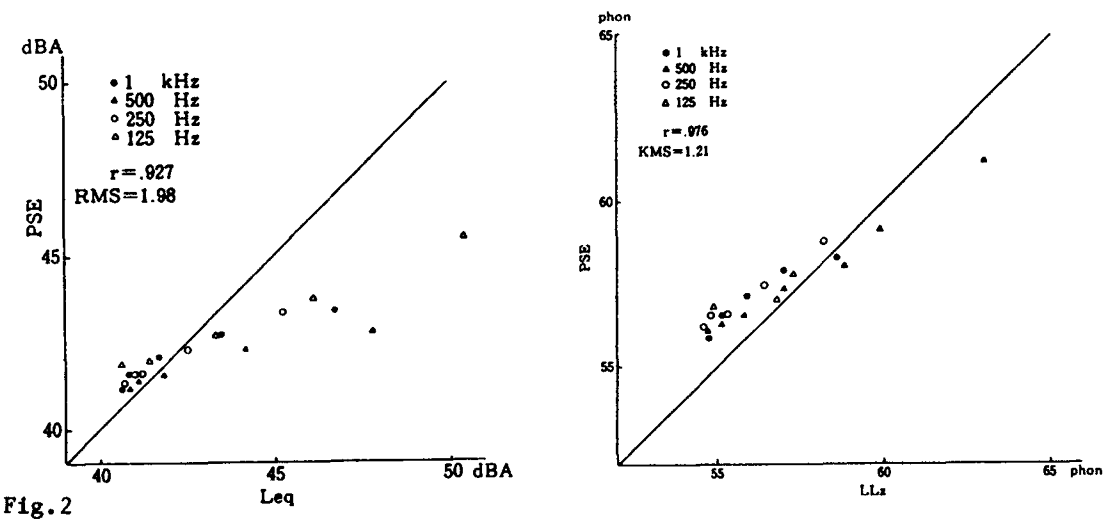


Fig.2

the propriety of sound exposure level (LAE) using several kinds of impulsive sound (Fig.5). It seems advisable to adopt a value based on the energy of sounds as a basic quantity. Where temporal factors of sound sources are involved, however, the temporal patterns of stimuli slightly but significantly affect loudness. The dynamic chracteristics of hearing must be taken into consideration. For example, Kumagai et al.[12] have suggested that the maximum value of a number of readings using a CR-circuit with several values of time-constants corresponds to loudness. According to their results, the optimal

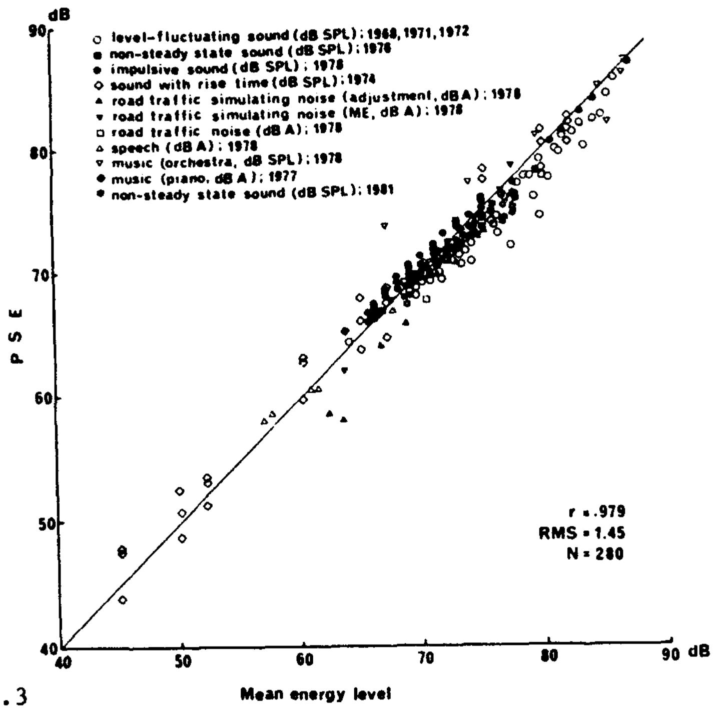


Fig.3

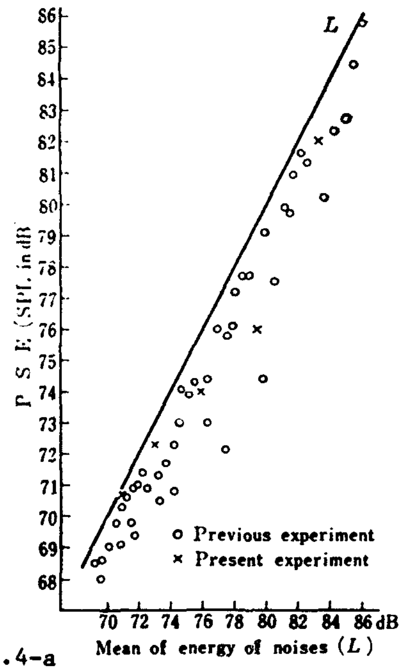


Fig.4-a

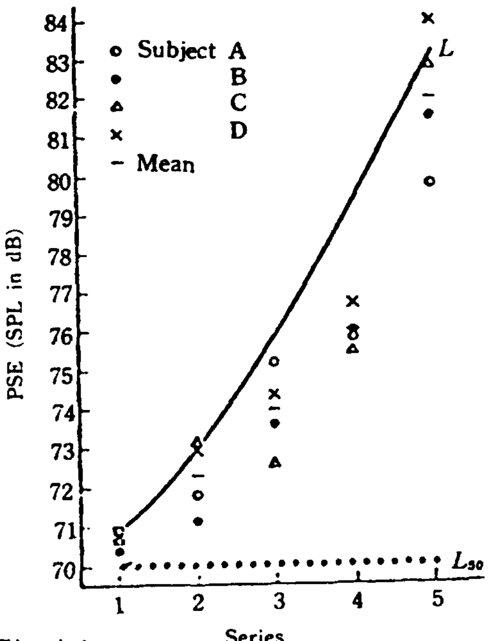


Fig.4-b

values of time constants changed according to stimulus conditions. It seems that the prediction of the optimal value of the time-constant for the evaluation of loudness of various kinds of impulsive noise is highly problematic.

There have been many experiments concerning the time constants of the auditory system, but many questions remain unanswered. Buus and Florentine[13] have reported that the auditory system may possibly have different time constants according to conditions. If this is so, it is difficult to decide on time-constants which can be used in the measurement of the loudness of all kinds of impulsive sound. Fastl[14] and Namba et al.[15] proposed schematic models of the dynamic characteristics of hearing (Figs. 6 and 7). But it is difficult to predict the loudness of all kinds of non-steady state noise from these models. At this stage, it seems appropriate that physical measurement should be made on a physical basis. Leq and LAE are very simple, based as they are on the physical value of energy.

Even in laboratory situations, there are still many other problems concerning the temporal pattern of stimuli and loudness. For example, the interaction between the envelope patterns of sounds when there are multiple sound sources in a room is a topic of interest and importance. As the phenomenon of co-modulation masking release[16] indicates, when the phase of the

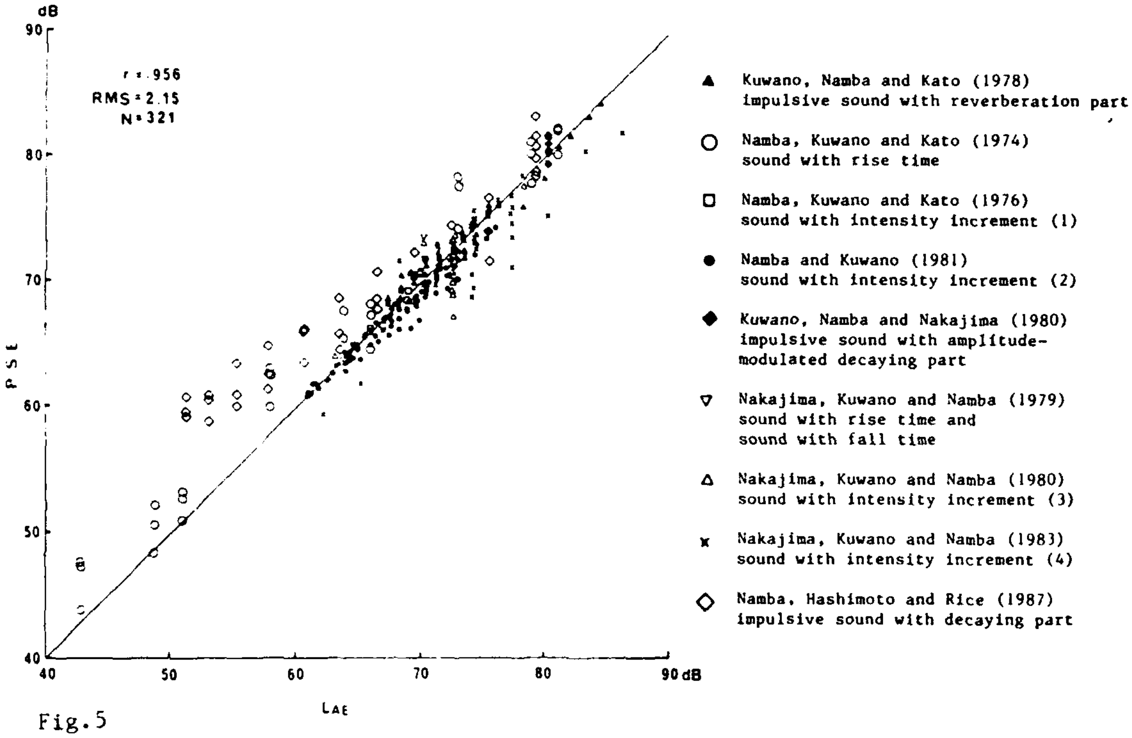


Fig.5

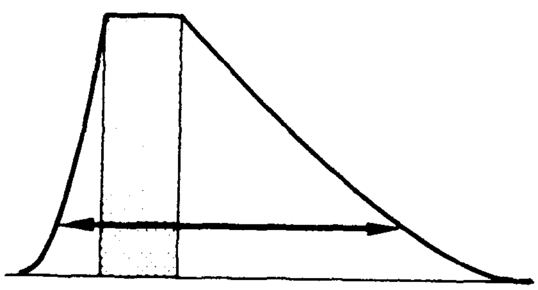


Fig.6

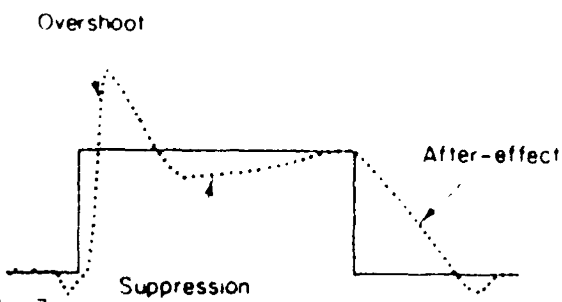


Fig.7

temporal fluctuation between the background noise and the signal is not synchronized, the amount of masking decreases greatly compared with the case when they are synchronized. This is related to noise evaluation, since better understanding of the temporal relation between noise and signal will increase the precision of prediction.

Any attempt to investigate the perception of noise from a temporal viewpoint must take long-term effects of noise on man into account. Factors which must be considered include the evaluation of temporal fluctuation of longer duration, the method of treating the effect of a number of events, and the time of day. All these are of fundamental importance to the exploration of the relation between temporal conditions and perception, both for the purpose of psychophysical inquiry and for applied research into temporally fluctuating and intermittent events occurring together over a period of time. A series of experiments using the method of continuous judgment by category developed by Namba et al.[17,18] is an example of research taking the domain of time into account (Fig.8). These topics are also examples of research where fundamental and applied approaches need to be combined.

In the case of daily life situations, we must take into account such factors as physical, physiological, psychological and social conditions. There is a limit to our ability to predict the effect of noise on man by physical measurement alone, and we must consider these other factors. In this case, it is doubtful whether loudness alone is an appropriate subjective index of the effect of noise. Other subjective indices must be included. For example, Kuwano et al.[19] have examined the relation between the noisiness of intermittent noises and the number of times of repetition. They found that noisiness is determined by both the Leq of intermittent noise, including the period of ambient noise, and the number of times of repetition, even though the duration of the stimuli was limited to within about 32 secs. This topic will be discussed later.

4. DIRECTIONALITY OF SOUND SOURCES

The evaluation of noise is usuallly based on sound level and frequency characteristics at the listening position, but for an accurate assessment it is necessary to take other factors besides these into account. It is now clear that the direction from which sound comes affects the way it is evaluated. This also applies to noise in a closed space such as a passenger car, where the effect of noise may vary depending on whether the irregular noise comes from the same direction as the engine noise or not. When directionality is to be taken into account, the technique of using a dummy head, as in architectural acoustics, is an effective method.

Jansen et al.[20] have shown that the binaural technique provides useful information concerning auditory spaciousness which affects physiological responses to noise. When sound comes from a number of different directions, stronger physiological effects are found. In the experiment, a dummy head recording was used and the factor termed "spatial distribution" was varied. As is shown in Fig.9, while subjects are exposed to multi-directional noise, the amplitude of the finger pulse does not reach the baseline. In the case of noise from one direction by contrast, the finger pulse amplitude returns to its

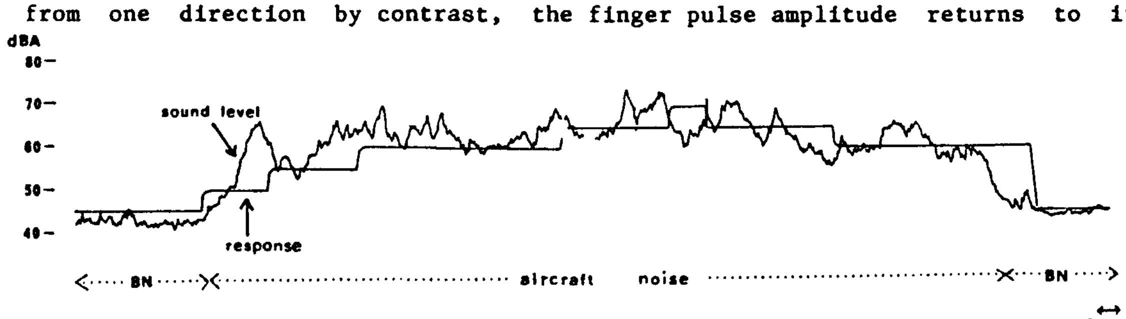


Fig.8

original level shortly after exposure to noise begins. This result suggests that subjects under multi-dimensional exposure conditions suffer more stress than under uni-dimensional exposure conditions.

This might be related to masking level difference. When the signal and noise come from different directions, it is possible that the masking decreases more than 10 dB. Under multi-dimensional exposure conditions, listeners hear various kinds of noise in an auditory environment. According to Blauert and Genuit,[21] binaural masked thresholds are about 2 to 15 dB lower compared with the results obtained by monaural measurements (Fig.10).

In factories, offices and even in houses, there are many machines. If it becomes possible to evaluate the overall effect of various noise sources in a given space, the trade-off effect can be measured quantitatively as well as qualitatively. This will give guidelines for the design of spaces which provide a comfortable environment in terms of sound. To evaluate the noise environments precisely, binaural techniques may be necessary.

5. DEFINITION OF NOISE

Psychophysical studies concerning the relation between physical parameters of sounds and subjective response in the laboratory situation are important. It is also important to consider personal and social factors. Noise is defined as "unwanted sound". The concept "unwanted" is extremely subjective and when

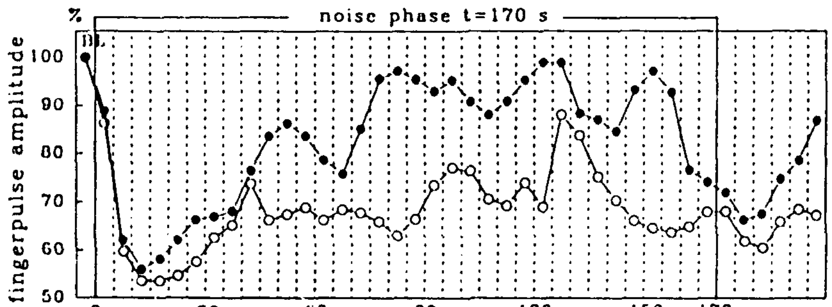


Fig.9 VR2; 5 subjects; ● unidirectional and O multidirectional presentation of two industrial noises (coupling machine and hacksaw); Baseline (BL): Arithmetic mean (AM) of the last 30 s before noise load (=100%); shown above the AM's of intervals of 5 s; AM during noise phase: ● 83.26 ± 32.03 % O 68.30 ± 25.50 %

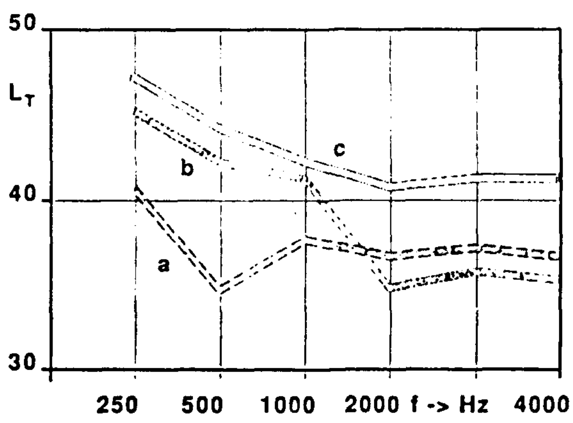
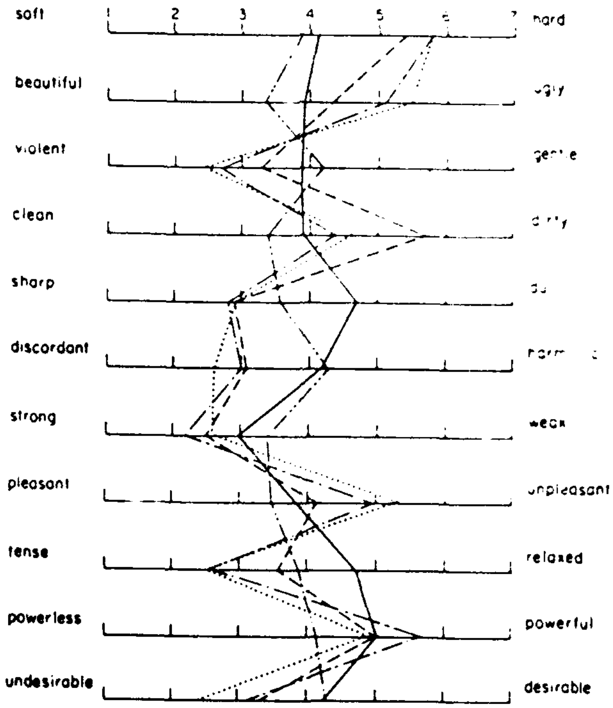


Fig.10 Masked threshold L_T Sound incidence 60°
Pink Noise L_M = 60 dB
a) free field b) diffuse field
c) monaural measurement

measures are to be taken against noise its subjective quality and meaning have to be taken into account. An appropriate criterion of "unwantedness" has to comprehend large individual differences. At present, noise in some societies is defined and evaluated only by means of statistics (ex. the percentage of the response of "highly annoyed"). It sometimes happens that a person or a group of people who suffer severely from noise must negotiate concerning it without outside support, which can cause social difficulties. To solve practical noise problems effectively in real life, personal conditions must be taken into consideration. It is not easy to apply, but clinical psychology may help in understanding the situation of noise sufferers.[22] On the technical side, an active noise control technique for personal space has been tested,[23] and may possibly contribute to solving this problem in future.

Needless to say, noise pollution is a social problem and a person's behavior is determined by his frame of reference, that is, the society he belongs to. Cultural background and social assumptions may be important factors in deciding whether sound is noise or not. It is essential to analyze the individual and social factors which determine the "unwantedness" of sounds in order to understand noise problems. To reach international agreement on noise problems, as well as on other environmental problems, a common understanding among different societies or countries is important. To achieve this, mutual communication is neccessary. One difficulty for this is that the connotative meanings of words in different languages cannot fully be understood from dictionaries. Several researchers from different countries have tried to define "loudness", "noisiness" and "annoyance" for the evaluation of the effects of noise on man, but there is no evidence that these terms have an equivalent meaning in different languages. The concept conveyed by the terms "loudness", "noisiness" and "annoyance" was judged using semantic differential in Japan, Germany, the U.K., the U.S.A. and China (Namba et al.[24]). Profiles for "noisiness" and "annoyance" in five countries are shown in Figs.11, 12 and 13.



Semantic profiles for "loudness" in Japan, West Germany, the U.K., the U.S.A. and China. ——, Japan; -·-, U.K.; ····, West Germany; - - -, U.S.A.; —··—, China.

Fig.11

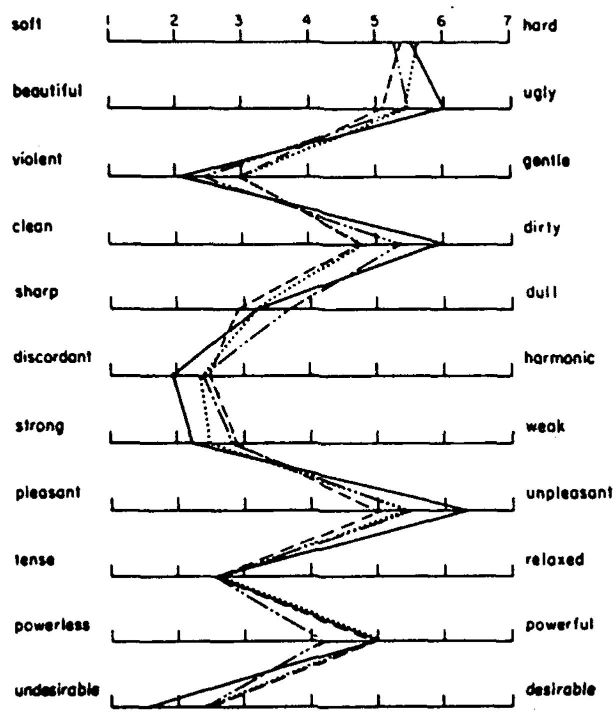


Fig. 12 Semantic profiles for "noisiness" in Japan, the U.K., the U.S.A. and China.

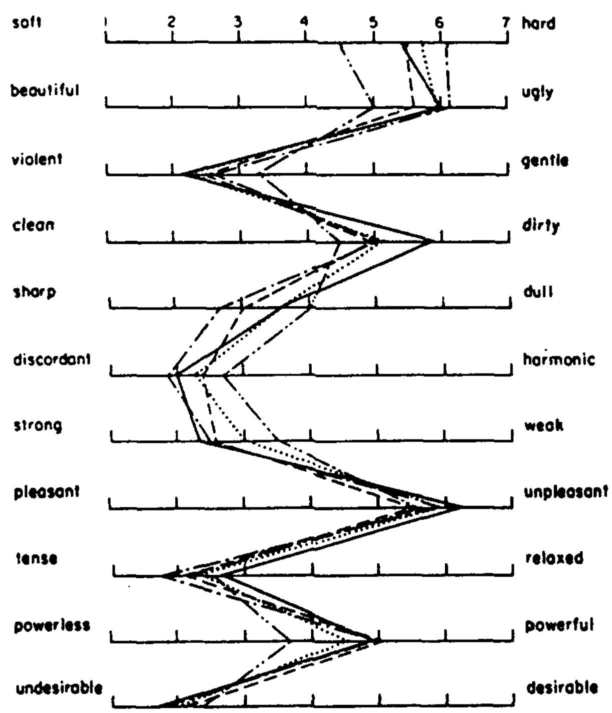


Fig. 13 Semantic profiles for "annoyance" in Japan, West Germany, the U.K., the U.S.A. and China.

In Japan and China, the connotative meaning of "loudness" was neutral, while those of "noisiness" and "annoyance" were negative and had similar profiles. The distinction between "loudness" and "annoyance" was unclear in Germany, and the distiction between "loudness" and "noisiness" in the U.K. and the U.S.A. It is difficult to disinguish these concepts by means of words alone. We need some explanation or operational definition of these concepts, agreed on internationally.

6. FINAL REMARKS

Noise is not the only component of an environment, of course, and from a wider viewpoint, it is necessary to synthesize the effects of all the factors which constitute an environment, and their interactions. It is desirable to investigate the effect of each factor, including visual perception, vibrotactile perception, olfactory perception and the perception of the quality of air, and their interactions. For example, Tamura et al.[25] have examined how "green belts" (woods) subjectively improve the auditory environment as well as the visual environment. Kastka et al. [26] have investigated the effect of the visual-aesthetic impression of a street-scene on noise evaluation.

Noise problems are an interdiciplinary study, and are related to ecological aspects of the environment. Their solution will be an international undertaking, calling for cross-cultural understanding.

To determine what effective countermeasures against noise are, we have to consider the following:

(1) The relation between cost and benefits in preventing environmental pollution. The possibility of finding measures to reduce noise without adding to the consumption of energy and resources.

(2) The importance of composite noise rating methods which precisely predict the effects of noise on man from physical measurements. These methods should take prominent frequency components, regular and irregular level-fluctuation and the directions of noise sources into consideration.

(3) The importance of personal, social and cultural backgrounds for evaluating the effects of noise on man.

(4) The need to establish theoretical models which take ecological values into account. For this, the coordination of basic and applied research is important.

ACKNOWLEDGEMENTS

The author is grateful to Professor Sonoko Kuwano of Osaka University for her kind discussion and cooperation.

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Approche psychologique de la recherche sur le bruit pour les besoins futurs.

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Résumé :

Le bruit n'est pas un problème global mais un problème typique d'environnement qui provoque une pollution sensorielle. Faire attention au bruit peut aider à développer une attitude moins superficielle à l'égard des problèmes d'environnement en général.
Afin de déterminer quelles seront les mesures efficaces contre le bruit, nous avons à prendre en compte ce qui suit :
. (1) La relation entre les dépenses et les bénéfices dans la prévention de la pollution.c'est-à-dire la possibilité de trouver des mesures pour réduire le bruit sans augmenter la consommation d'énergie et de ressources.
(2) L'importance des méthodes d'estimation des bruits complexes qui prédisent précisement les effets du bruit sur l'homme par des mesures physiques. Ces methodes pourront prendre en considération les composants remarquables des fréquences,les fluctuations de niveau régulières ou irrégulières et les directions des sources de bruit
(3) L'importance des antécédents personnels, sociaux et culturels pour évaluer les effets du bruit sur l'homme.
(4) La nécessité d'établir des modèles théoriques qui prendront en compte des valeurs écologiques. Pour celà, la coordination entre les recherches fondamentale et appliquée est importante.

1. Introduction

La pollution de l'environnement est un problème mondial et une voie importante pour son traitement passe par la sauvegarde de l'énergie et des ressources. Des restrictions entraîneraient beaucoup d'inconvenients et pourraient même menacer des choses que nous considérons comme une partie intégrante de notre vie moderne. Si nous espérons maintenir un niveau de vie confortable sans causer de destruction à notre environnement, nous devons développer des techniques nouvelles qui ne seront pas basées sur la consommation et qui pourront contribuer à préserver l'énergie et les ressources.
S'il est raisonnable de proposer cette mesure, sa mise en application pratique devra faire face à de nombreuses difficultés. L'une d'elles est qu'il n'est pas facile d'obtenir un agrément général entre les nations sur le partage des dépenses. Une autre est que les compagnies industrielles qui développent des nouvelles technologies pour la protection de l'environnement, après des investissements énormes, n'aimeront probablement pas les rendre disponibles sans quelques retours financiers. Enfin, les pays développés qui ont beaucoup de ressources espéreront les exploiter pour parfaire un niveau de vie élevé.
Pour protéger notre environnement et améliorer ses conditions, nous devons reconnaître que nous avons à partager les charges du coût et des efforts. Pour celà, nous devons adopter une attitude déterminée face aux problèmes d'environnement.
Le bruit n'est pas un problème mondial. L'energie sonore n'est pas accumulée et l'aire de gêne due au bruit est concentrée autour de sa source. Pourtant, les effets du bruit sur l'homme ne sont pas sans importance, comme ceux qui souffrent seront prêts à en témoigner.
Beaucoup de machines qui font du bruit sont couramment utilisées dans de nombreux pays et peuvent être la cause de problèmes de bruit. L'acoustique peut répondre à ces problèmes. Mais, comme pour les solutions aux autres problèmes de pollution,cela ne se fera pas sans dépenses et nous avons à prendre en compte la relation entre les coûts et les bénéfices.
Le bruit est une pollution sensorielle. Tout le monde peut reconnaître ses effets nocifs sans l'utilisation d'instruments de mesure. En faisant attention, chacun à son niveau peut contribuer

à la prévention du problème et l'efficacité des mesures techniques sera facilement perçue. Dans une certaine mesure, le bruit est un problème typique d'environnement mais ses causes, ses conséquences et ses solutions sont plus évidentes pour les personnes ordinaires. Faire attention au bruit peut aider à développer une attitude moins superficielle à l'égard des problèmes d'environnement en général.

Les mesures contre le bruit qui nécessitent des grandes dépenses d'énergie et de ressources ne peuvent pas être adoptées même si elles sont très efficaces. Par exemple, le bruit de conditionnement d'air diminue quand la vitesse des ventilateurs est réduite mais celà diminue l'efficacité de l'appareil. Une meilleure solution est possible, bien qu'elle soit plus difficile à mettre en oeuvre : le bruit peut être réduit sans réduire la performance en créant des ventilateurs d'un modèle plus efficace. Ceci est juste un exemple parmi plusieurs pour montrer comment les mesures contre le bruit sont à considérer en fonction de l'énergie et des ressources.

Pour arriver à la solution la plus efficace, les facteurs psychologiques doivent être pris en compte.

D'un point de vue psychologique, quelques caractéristiques physiques du bruit ont des significations spéciales. Des méthodes plus précises pour prédire les effets du bruit sur l'homme ont été developpées. L'une d'elles implique la découverte d'indices de bruit plus précis basés sur la relation entre les paramètres physiques du son et les réponses subjectives des individus.

2 . La correction fréquentielle

La pondération-A est couramment adoptée dans la mesure du bruit et dans les réglementations sur le bruit. La pondération-A est approximativement la fonction inverse de la courbe de niveau d'égale intensité à 40 phonies. Il n'y a aucune raison théorique pour généraliser l'utilisation de la pondération-A.

Plusieurs méthodes de calcul de l'intensité basées sur des modèles psychologiques et des découvertes expérimentales ont été proposées.

Parmi elles la méthode de Stevens (LLs) et la méthode de Zwicker (LLz) qui ont été adoptées dans l'ISO 532 pour calculer le niveau d'intensité de sons stables à large bande. Ces méthodes ont quelques fondements théoriques.

Le LLz est une sorte de simulation de la membrane basilaire de l'oreille interne. La procédure pour calculer le LLz est très compliquée et son utilisation dans des applications pratiques n'est pas à la portée de tous, même si un modèle simplifié a été développé pour les ingénieurs. Un programme informatique pour calculer le LLz est devenu disponible récemment au Japon (Zwicker et al.) qui facilite son utilisation pour des applications pratiques.

Il existe des expériences réalisées par Namba et Kuwano concernant l'intensité des différentes sortes de sons non stables dans lesquelles les propriétés du niveau de pression acoustique pondéré A (dB(A)), le LLs et le LLz ont été comparés. Le LLs et le LLz montrent une meilleure correspondance avec l'intensité perçue que le dB(A) même si la différence n'est pas très grande. Mais dans les applications pratiques, la simplicité est aussi importante que la précision et dans cette optique le dB(A) a quelques avantages.

Toutefois, pour les sons qui ont des composantes importantes dans quelques zones de fréquences, le LLz montre une correspondance meilleure avec l'intensité que le dB(A). Par exemple, comme il est montré dans la figure 1, dans le cas d'un bruit large qui est fortement composé de sons purs avec des modulations d'amplitude, le LLz est un meilleur indice que le dB(A). Une tendance similaire a été trouvée dans le cas d'un bruit large bande composé de sons purs modulés (Fig. 2 : bruit de l'air conditionné). Ces résultats fournissent un guide très utile pour l'évaluation du bruit des machines et pour la conception de machines où la réduction du bruit est une considération importante.

Pour une prévision précise de l'intensité, les méthodes basées sur les analyses en octave ou en 1/3 d'octave sont meilleures que les méthodes pour lesquelles un seul canal de mesure, comme le dB(A), est utilisé.

Dans le cas de celles-ci, on peut améliorer la précision pour la recherche fondamentale sur le mécanisme de l'audition et pour l'avancement du traitement de l'intensité des sons complexes.

Les effets possibles de l'échelle d'intensité, des modèles de masquage, de masquage partiel, de recrutement dans les basses fréquences et des fréquences critiques ont besoin d'être considéré avec plus d'attention. Des coopérations plus grandes sont souhaitables entre la recherche fondamentale sur l'audition et la recherche appliquée.

3 . Evaluation des sons non stables

L'ISO 532 n'est applicable qu' aux sons stables. Dans les situations de la vie quotidienne, toutefois, la plupart des sons sont des variantes de sons instables, comme le bruit de trafic routier, le bruit des avions, le bruit des trains, le bruit des chantiers, la musique et la parole.
Il est important de décider d'une valeur représentative pour toutes ces fluctuations de niveau. Les normes japonaises de l'industrie, JIS Z8731, et ISO 2204-1973 définissent plusieurs sortes de fluctuations de niveau.
JIS Z8731 recommande le Leq (niveau de pression équivalent pondéré A en décibels) aussi bien que le Lx (niveau en pourcentage) pour le mesurage de bruit fluctuant. Namba et Kuwano et al. ont recherché les avantages du Leq comme mesure de l'intensité des différentes sortes de bruit instables en comparaison avec le Lx. Comme il est montré dans la Fig. 3, le Leq présente une bonne corrélation avec l'intensité. Dans quelques conditions d'excitations, où la valeur du Lx est constante et les distributions de fluctuation de niveaux variables, il n'y a pas de corrélation entre le Lx et l'intensité comme nous le montre la Fig. 4. Malgré tout, au Japon, le Lx est toujours utilisé pour la réglementation des bruits dans l'environnement pour des raisons pratiques, mais je suis convaincu que le Leq remplacera le Lx dans un futur proche.

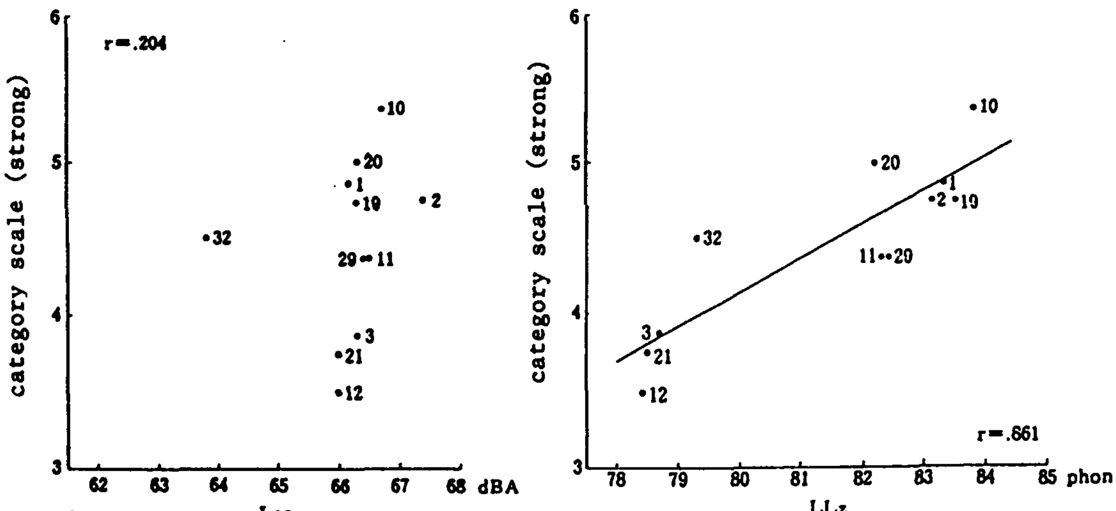


Fig.1

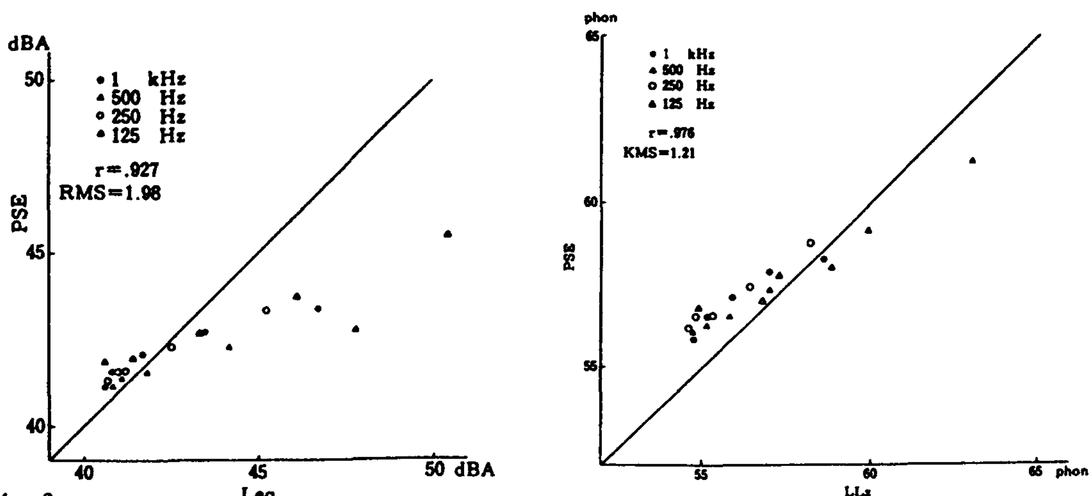


Fig.2

Pour l'évaluation des sons impulsionnels, Kuwano et Namba ont confirmé les propriétés du niveau d'exposition au bruit (LAE) utilisant plusieurs sortes de bruits (Fig. 5). Il semble judicieux d'adopter une valeur basée sur l'énergie des sons comme quantité fondamentale. Toutefois, lorsque des facteurs temporels des sources sonores sont impliqués, les modèles temporels des excitations affectent légèrement mais de manière significative l'intensité. Les caractéristiques dynamiques de l'audition doivent être prises en considération. Par exemple, Kumagai et al. ont suggéré que le nombre maximal de lectures utilisant un circuit-CR avec plusieurs valeurs de constantes de temps correspond à l'intensité. Suivant leurs résultats, la valeurs optimale des constantes de temps change suivant les conditions d'excitation. Il semble que la prédiction de la valeur optimale de la constante de temps pour l'évaluation de l'intensité des différentes sortes de bruits impulsionnels soit hautement problématique.

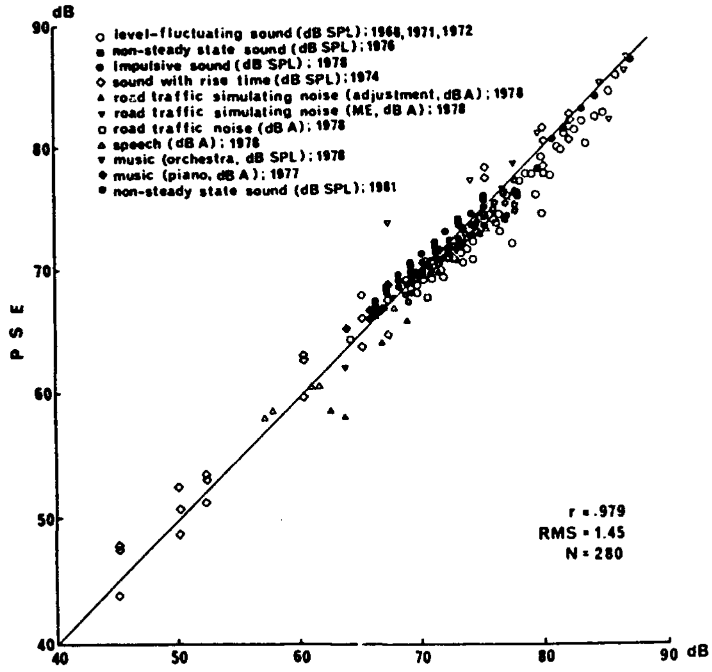


Fig.3

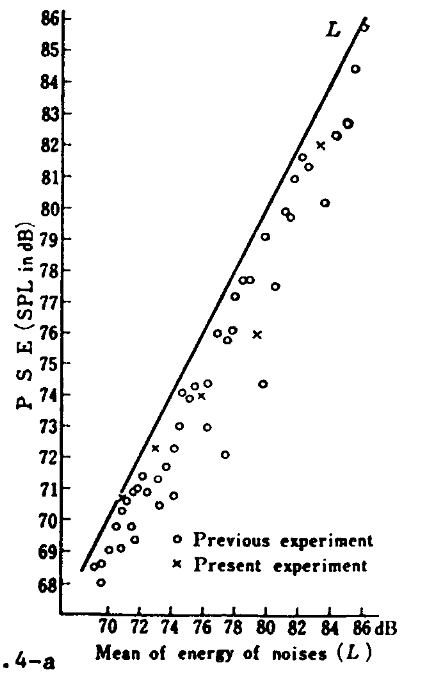


Fig.4-a

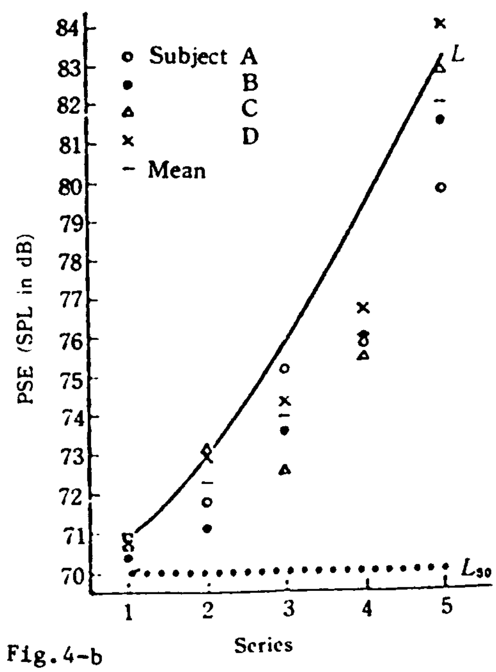


Fig.4-b

Il y a eu beaucoup d'expériences concernant les constantes de temps du système auditif, mais beaucoup de questions restent sans réponse. Buus et Florentine ont rapporté que le système auditif pourrait avoir des constantes de temps différentes suivant certaines conditions. Si celà est vrai, il est difficile de décider de la constante de temps à utiliser pour la mesure de l'intensité de toutes les sortes de bruits impulsionnels. Fastl et Namba et al. ont proposé un modèle schématique des caractéristiques dynamiques de l'audition (Fig. 6 et 7). Mais il est difficile de prédire l'intensité des bruits non-stables avec ces modèles.
A ce stade, il paraît judicieux que la mesure soit faite sur une base physique. Le Leq et le LEA sont très simple, car ils sont basés sur la valeur physique de l'énergie.
Même dans des situations de laboratoire, il y a encore beaucoup d'autres problèmes concernant le modèle temporel des excitations et de l'intensité. Par exemple, l'interaction entre les modèles d'enveloppe des sons quand il y a des sources multiples de bruit dans une pièce est un thème d'interêt et d'importance. Comme le phénomène de comodulation de décharge masquante l'indique, lorsque la fluctuation temporelle entre le bruit de fond et le signal n'est pas synchronisé, le total du masquage décroit fortement comparé au cas où ils sont synchronisés. Ceci à un rapport avec l'évaluation du bruit, puisque une meilleure compréhension de la relation temporelle entre le bruit et le signal augmente la précision de la prédiction.

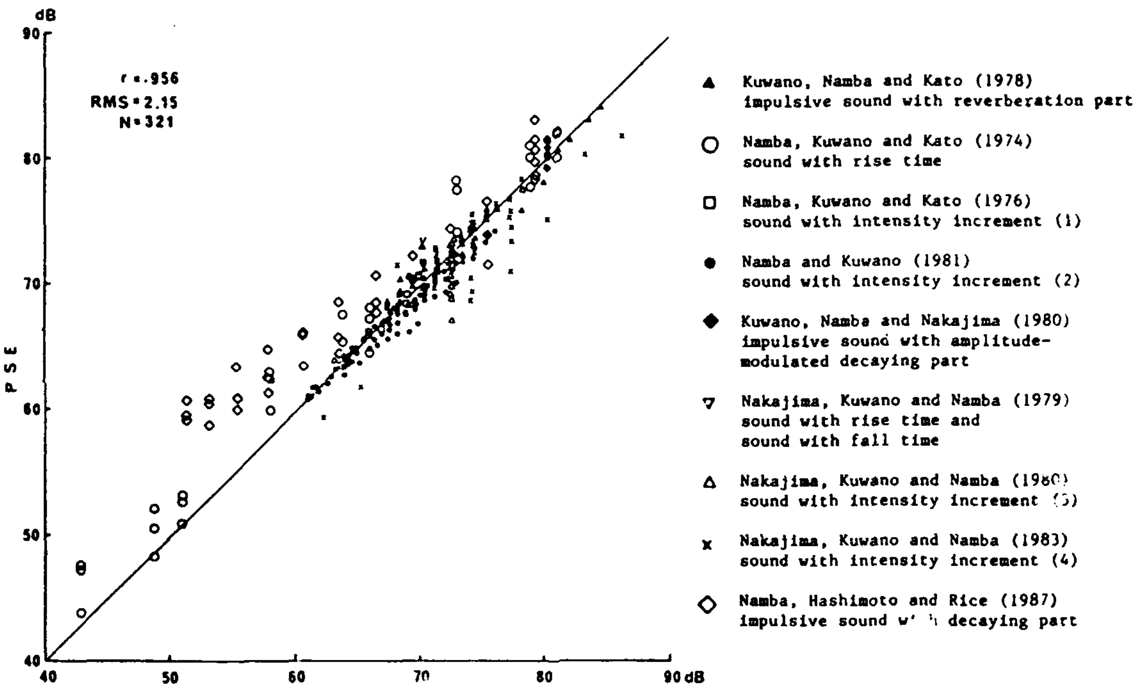


Fig.5

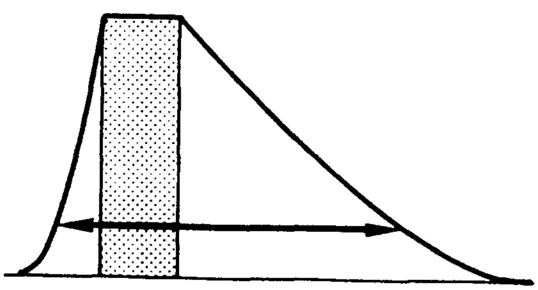


Fig.6

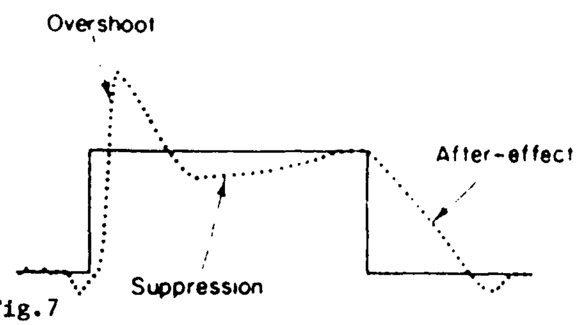


Fig.7

Chaque tentative pour étudier la perception du bruit du point de vue temporaire doit prendre en compte les effets à long terme du bruit sur l'homme. Les facteurs qui peuvent être considérés incluent l'évaluation des fluctuations temporelles de longue durée, la méthode pour traiter l'effet d'un nombre d'évènements, et le moment de la journée. Tous ces facteurs ont une importance fondamentale pour l'exploration simultanée de la relation entre les conditions temporelles et la perception pour les besoins de l'enquête psychophysique et pour la recherche appliquée aux évènements intermittents et temporairement fluctuants apparaissant ensemble sur une certaine durée. Une série d'expériences, utilisant la méthode des jugements continus par catégorie, developpée par Namba et al. est un exemple de recherche prenant en compte la donnée Temps (Fig. 8). Ces thèmes sont aussi des exemples de recherche où les approches fondamentale et appliquée doivent être combinées.
Dans le cas de situations courantes, nous devons prendre en compte des facteurs tels que les conditions physiques, physiologiques, psychologiques et sociales. Il y a des limites à notre capacité de prédire les effets du bruit sur l'homme seulement par des mesures physiques, et nous devons considérer les autres facteurs. Dans ce cas, il est douteux que seule l'intensité soit un indice subjectif approprié des effets du bruit. D'autres indices subjectifs doivent être inclus. Par exemple, Kuwano et al. ont examiné la relation entre le caractère bruyant des bruits intermittents et le nombre d'apparitions. Ils ont trouvé que le caractère bruyant est déterminé à la fois par le Leq des bruits intermittents comprenant la période de bruit ambiant, et le nombre d'apparitions même si la durée des stimuli se situe dans une limite de 32 secondes. Ce sujet sera discuté ultérieurement.

4. La directivité des sources sonores

L'évaluation des bruits est basée habituellement sur les niveaux de bruit et les caractéristiques fréquentielles en position d'écoute, mais pour une estimation exacte il est nécessaire de prendre en compte d'autres facteurs encore.
Il est clair maintenant que la direction de laquelle arrive le bruit affecte la façon dont il est évalué. Celà s'applique aussi au bruit dans un espace clos tel qu' une voiture où les effets du bruit doivent varier suivant que le bruit irrégulier vient de la direction du moteur ou pas. Lorsque la directionnalité est prise en compte, la *technique de la tête de mannequin* comme en acoustique architecturale est une méthode efficace.

Jansen et al. ont montré que la technique binaurale fournit des informations utiles concernant la spatialité qui affectent ses réponses physiologiques au bruit. Quand les sons arrivent de différentes directions, des effets physiologiques plus marqués sont trouvés. Dans l'expérience, un enregistreur en forme de tête de mannequin était utilisé et le facteur appelé "distribution spatiale" était variable. Comme il est montré dans la fig. 9, tant que les sujets sont exposés à des bruits multi-directionnels, l'amplitude du rythme des doigts n'atteint pas le minimum. Par opposition, dans le cas de bruit provenant d'une seule direction, l'amplitude du rythme des doigts revient à son niveau original peu de temps après le commencement de l'exposition au bruit.

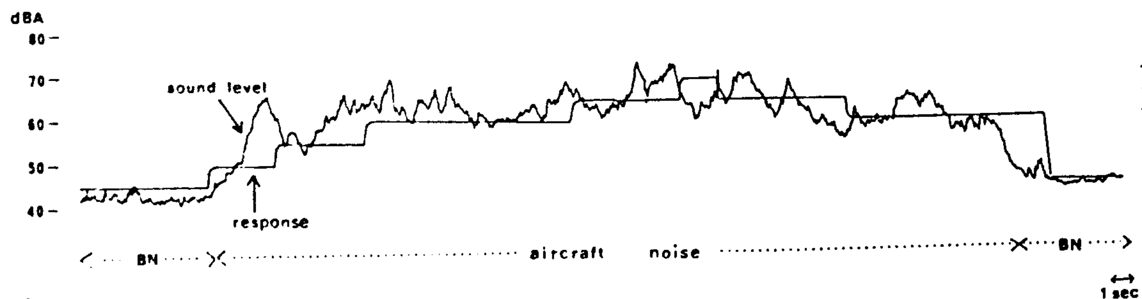
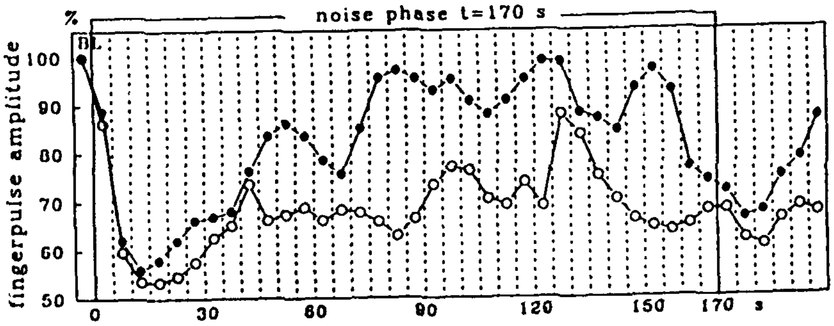


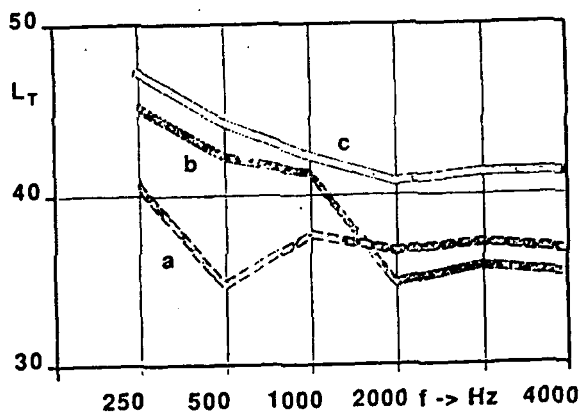
Fig.8

Ce résultat suggère que les sujets soumis à une exposition multi-dimentionnelle souffrent plus du stress que ceux exposés à des conditions uni-directonnelles.
Ceci doit avoir un rapport avec le niveau de bruit masquant. Quand le signal et le bruit viennent de différentes directions, il est possible que l'effet de masque décroisse de plus de 10 dB. Sous des conditons d'exposition multidimensionelle, les auditeurs entendent différentes sources de bruit dans un environnement auditif. D'après Blauert et Genuit, les seuils de masquage binaural sont de 2 à 15 dB inférieurs à des résultats obtenus par des mesures monaurales. (Fig. 10).
Dans les usines, les bureaux et même dans les maisons, il y a beaucoup de machines. S'il est possible d'évaluer les effets globaux des différents sources de bruit dans un espace donné, l'effet alternatif peut être mesuré de façon quantitative autant que qualitative. Ceci donnera des règles pour la conception d'espaces pouvant assurer un environnement confortable en terme de bruit.
Pour évaluer les environnements bruyants de manière précise, la technique binaurale peut être nécessaire.



VR2; 5 subjects; ● unidirectional and ○ multidirectional presentation of two industrial noises (coupling machine and hacksaw); Baseline (BL): Arithmetic mean (AM) of the last 30 s before noise load (=100%); shown above the AM's of intervals of 5 s; AM during noise phase: ● 83,26 ± 32,03 % ○ 68,30 ± 25,50 %

Fig.9

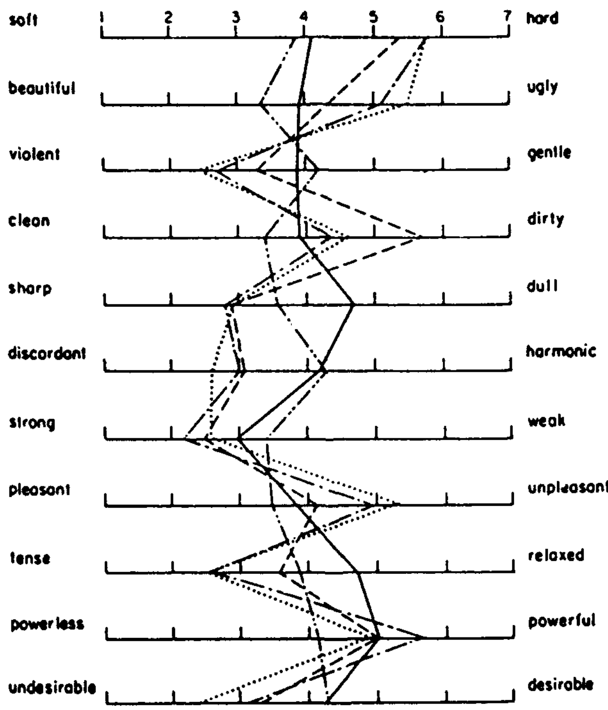


Masked threshold L_T Sound incidence 60°
Pink Noise L_M = 60 dB
a) free field b) diffuse field
c) monaural measurement

Fig.10

5. Définition du bruit

Les études psychophysiques menées en laboratoire sur la relation entre les paramètres physiques du bruit et la réponse subjective sont importantes. Il est aussi important de considérer les facteurs personnels et sociaux. Le bruit est défini comme un son non désiré. Le concept "non désiré" est extrêmement subjectif et quand on décide des mesures de lutte contre le bruit, sa qualité subjective et sa signification doivent être prises en compte. Un critère approprié de "non désirabilité" doit inclure de grande différences individuelles. A présent, le bruit dans certaines sociétés est défini et evalué seulement en terme de statistiques (ex. : le pourcentage de réponse de "très gênés"). Il arrive quelquefois qu'une personne ou un groupe de personnes qui souffre terriblement du bruit doive lutter sans aide extérieure ce qui peut causer des difficultés sociales. Pour résoudre des problèmes concrets de bruit arrivant dans la vie courante, les conditions personnelles doivent être prises en considération. Ceci n'est pas facile à expliquer, mais la psychologie clinique peut aider à comprendre la situation des personnes qui souffrent du bruit. Du côté technique, des appareils de contrôle actif pour des espaces personnels ont été testés, et pourront peut être contribuer à résoudre ces problèmes dans le futur.



Semantic profiles for "loudness" in Japan, West Germany, the U.K., the U.S.A. and China. ——, Japan; - · -, U.K.; · · · ·, West Germany; - - -, U.S.A.; — · · —, China.

Fig.11

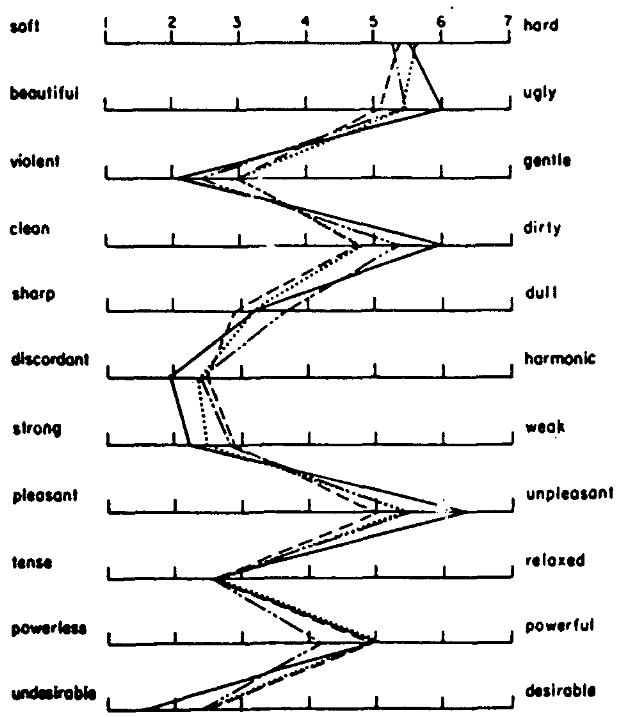


Fig.12 Semantic profiles for "noisiness" in Japan, the U.K., the U.S.A. and China.

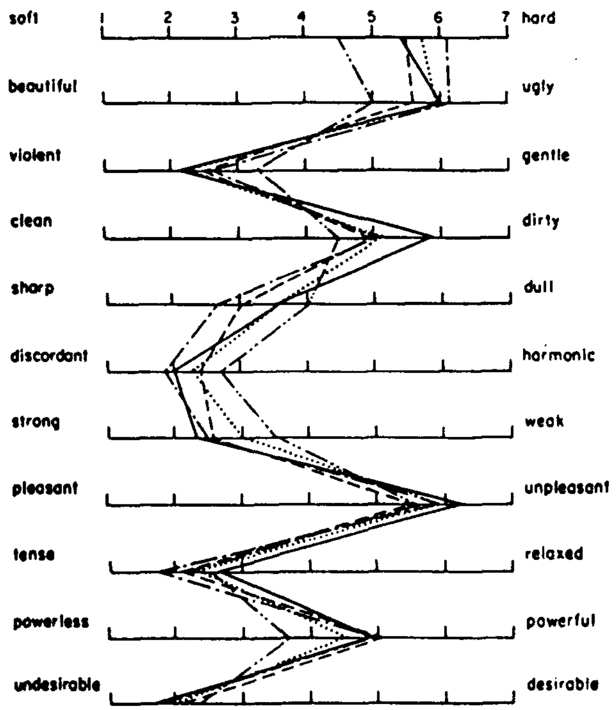


Fig.13 Semantic profiles for "annoyance" in Japan, West Germany, the U.K., the U.S.A. and China.

Il est inutile de dire que le bruit est un problème social et que notre comportement personnel est déterminé par sa structure de référence c'est à dire la société à laquelle nous appartenons. Le contexte culturel et les affectations sociales peuvent être des facteurs importants lorsqu'on décide si tel son est du bruit ou non. Il est essentiel d'analyser les facteurs individuels et sociaux qui déterminent la nondésirabilité des sons afin de mieux comprendre les problèmes de bruit. Pour obtenir un agrément international sur les prbolèmes de bruit, comme sur les autres problèmes d'environnement, une compréhension commune dans les différentes sociétés ou pays est importante. Pour terminer, une communication mutuelle est nécessaire. Une des difficultés pour celà est que les significations connotative des mots dans les différents langages ne peuvent complètement être comprises à partir de dictionnaires. Plusieurs chercheurs de différents pays ont essayé de définir l'intensité, la bruyance et la gêne pour l'évaluation des effets du bruit sur l'homme, mais il n'est pas évident que ces termes aient un sens équivalent dans différents langages. Les concepts véhiculés par les termes intensité, bruyance et gêne étaient jugés comme étant de sémantique différente au Japon, en Allemagne, en Grande-Bretagne, aux USA et en Chine (Namba et al.). Les profils de bruyance et gêne dans 5 pays sont montrés dans les figures 11, 12 et 13.
Au Japon et en Chine, la signification connotative d'intensité était neutre, alors que celles de bruyance et de gêne étaient négatives et avaient un profil similaire. La distinction entre bruyance et gêne n'est pas claire en Allemagne, ainsi que la distinction entre intensité et bruyance en GB et aux USA. Il est difficile de distinguer ces concepts par la signification des noms seuls. Nous avons besoin de quelques explications ou définitions opérationnelles de ces concepts, agréées au niveau international.

6. Dernières remarques

Le bruit n'est pas le seul composant de l'environnement, bien sûr, et d'un point de vue plus large, il est nécessaire de synthétiser les effets de tous les facteurs qui constituent un environnement et leurs interactions. Il est souhaitable de rechercher les effets de chaque facteur, incluant la perception visuelle, vibrotactile, olfactive et la perception de la qualité de l'air et leurs interactions. Par exemple, Tamura et al. ont examinés comment les ceintures vertes (bois) *améliorent subjectivement l'environnement auditif* aussi bien que l'environnement visuel.
Kastka et al. ont recherché les effets de l'impression esthétique qu'on a d'une rue sur l'évaluation du bruit.
Les problèmes de bruit relèvent d'une étude interdisciplinaire, et sont reliés aux aspects écologiques de l'environnement. Leurs solutions seront des entreprises internationales nécessitant une compréhension inter-culturelle.

Remerciements : L'auteur remercie le professeur Sonoko Kuwano de l'université d'Osaka pour son aimable coopération.

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DEVELOPMENTS IN NOISE-INDUCED HEARING LOSS DURING THE LAST 25 YEARS

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At the time of the first Conference on Noise as a Public Health Hazard (the term "hazard" was changed to "problem" only at the second conference), we already knew quite a bit about the effects of noise on hearing--or perhaps I should say that we were conscious of how little we knew. I summarized the situation as follows: "Steady noises above 80 dBA are capable of producing some change in auditory threshold, and above 105 dBA they are sure to produce PTS in the normal unprotected ear if exposure continues, eight hours a day, for several years. We cannot reduce NIPTS except by reducing the effective noise exposure, and there is no way to restore it. Furthermore, we cannot identify the noise-susceptible individual. Therefore pre-employment and monitoring audiometry, together with a program of ear protection, is the only solution now known." As we shall see, many of these somewhat pessimistic generalizations are still true.

However, before I try to summarize the scientific progress we have made in the intervening 25 years, let me say a few words about the practical aspects of our common goal: to eliminate, or at least minimize, the hearing loss caused by noise in our society. In 1968 we had just gotten started on programs to limit exposure to workplace noise, but already it was clear that the noises of everyday life were often more hazardous than these industrial noises. Although it was possible to limit workers' exposures by regulation, other methods for persuading the average citizen to protect his hearing, either by avoiding loud sounds or using hearing protective devices, had to be devised.

Any program of education of the general public about the hazards of noise had several generally-held misconceptions to overcome. Probably the most dangerous one is that hazard depends only on level and not on duration. You will perhaps recall that the august Congress of the USA, in all seriousness, mandated in the Noise Control Act that the Environmental Protection Agency was to "determine those levels, the attainment and maintenance of which are necessary to protect the public health and welfare with an adequate margin of safety." So one problem was to teach those who would regulate their fellows that exposure to high levels is safe if the duration is short enough. On the other hand, the man in the street tends to think that if a noise is not uncomfortably loud, it poses no hazard no matter how long he is exposed to it. Thus we had somewhat antithetical objectives: convince legislators to worry less about levels but persuade everyone else to worry more about duration of exposure. I am not sure that we have succeeded completely in this endeavor, but progress has certainly been made. Hearing protectors are now much more socially acceptable than in 1968: plugs or muffs are worn without protest not only by the jackhammer operators whose din stirred Alex Barron to become a crusader against noise, but by many homeowners while mowing the lawn, cutting wood with a chain saw, and, occasionally, even while operating a snowmobile, although the latter area involves the "macho" attitude--"Sure it's loud, but I'm tough and I can take it". The last vestiges of that attitudestill have not disappeared in industry, but it certainly is less prevalent than it was 25 years ago.

Where success has been greatest is in the field of recreational shooting. Hardly anyone will participate in competetive shooting without hearing protectors. Of course, this isn't so much because of our effective teaching--although we would like to think we helped--but rather a matter of good fortune in that wearing protectors,in eliminating the startle reflex, produces higher scores. There's nothing like a good secondary reinforcer.

This is not to say that problem areas do not still exist that appear hopeless. The broadest of these areas is that of music. Our young people--many of them, at least--simply want to hear music at a level sufficient to arouse a visceral response; they want to feel the music. So they crank up their Walkman as high as possible, demand concert levels of 115 dBA or more, and mount high-powered audio systems in their cars. It does no good, in my experience, to point out that they will still get the feeling from the high-intensity sounds even if they are wearing protectors. The situation is not usually helped by exaggeration of the hazards of music exposure by the popular press either, when they bemoan the fact that some well-known rock musician has a hearing loss and imply that that's what will happen to anyone who is exposed even only occasionally to these 115-dB levels. Again, this illustrates the confusion constantly being engendered by ignoring duration when discussing the hazards of high-intensity sounds.

All this is an example of the "overkill" or "Chicken Little" phenomenon that permeates our society. If anything is bad for you in large doses, the media promote the notion that small doses are also hazardous (unfortunately, there are "scientists" who do the same thing, but I hope there are none of these individuals here). So, for example, if cigarette smoking often leads to lung cancer, we should keep anyone from breathing even much-diluted second-hand smoke. And on occasion the public mass hysteria can be turned on by evidence that is unbelievably flimsy, as witness the current furor about the alleged hazards of ordinary electromagnetic radiation from power lines, transformers, and even normal house wiring. It is probably going to occur to some newperson that when we travel, we cut all those lines of magnetic flux, and we will be warned against excessive travel, especially at high speeds, or it may affect our "aura".

All in all, however, our field has not been afflicted with much of this type of obvious gobbledegook, although overkill does appear here and there. For example, many industries do not want to take the trouble to calculate whether or not workers are overexposed, so they simply establish "noise zones"--usually, any place with a level of 90 dBA or more--and require everyone to wear protection while in that noise, if only for a few seconds. Once again the most basic principle of the noise-and-hearing arena is involved--i.e., ignoring duration as a vital component of noise dose.

Of course, perhaps this pernicious neglect of the factor of time in assessing hazard comes from the fact that it is not nearly as important in other facets of noise pollution such as annoyance. The neighbor's dog may be just as annoying after the first bark as after five minutes of incessant vocalization. I have no doubt that it was the preoccupation with annoyance from noise that led the framers of the Noise Control Act to ignore duration completely.

Let me return to the topic of progress in the field of noise-induced hearing loss from the scientific point of view--i.e., to what extent have we made progress in understanding, predicting, controlling and eliminating it? At the second Congress in Dubrovnik I posed a series of questions that I hoped would be addressed there; let me repeat these questions here and comment briefly on present state.

(1) Can there be damage to hearing without a change in sensitivity? A couple of decades of study of this possibility has so far not produced anything more than "promising" results. It is true that in an ear with a loss of sensitivity there are accompanying phenomena such as degradation of frequency selectivity, but noise exposure has not yet been shown to produce such a change, of a permanent nature, if the threshold sensitivity has completely recovered.

(2) What single exposure (8 hr or less) will just produce a 'significant' permanent threshold shift? We still have no idea where this threshold lies, in the case of man; the problem can be attacked experimentally only in laboratory animals. 138 dB for a couple of seconds (the ring of a cordless telephone) can produce a significant loss in a few highly susceptible individuals, but 153 dB for 0.4 seconds generated only a very moderate TTS, as did 135-dB jet noise for a minute. The threshold for damage in the chinchilla appears to be about the energy in an 8-h exposure at 90 dBA.

(3) What relatively steady-state exposure, 8 hr/day, for many years, will just produce PTS that exceeds that ascribable to presbyacusis plus sociacusis? (I should have said also to nosoacusis, but I had not yet invented the term). The data are relatively unequivocal in saying that this level is 80 dBA in man. Although some still argue that this "threshold" is 75 dBA, they forget that the effect they are dealing with is the result of the joint action of workplace noise and the noises of everyday life.

(4) Is there any way to correct audiometric data for presbyacusis-plus-sociacusis other than simple (and probably incorrect) subtraction? We are still working on this important but possibly unsolvable problem. Correction on the basis of additivity seems to work, even though sociacusic and industrial noises must be affecting the same elements in the auditory mechanism, in which case additivity of effect cannot be expected, but only additivity of effectiveness.

(5) Under what conditions does the equal-energy hypothesis hold for steady exposures? In the chinchilla, at least, for single uninterrupted ones. This was something of a "planted" question, as we were at that time working on it. It turned out that it was true not only for single uninterrupted exposures, but also for single uninterrupted daily exposures, for all practical purposes. Only when the daily exposure is intermittent does the equal-energy theory fail.

(6) Can individual differences in susceptibility to PTS be predicted? After a multitude of studies, the answer remains "not very well". PTS at some frequency range may be significantly correlated to TTS in a frequency range that is still normal in sensitivity, and TTS from a given noise spectrum may predict PTS from more severe exposures to that same noise. There are also indications that susceptibility depends on eye color, gender, and other fixed

characteristics of the individual, but the predictive value is only slight. Furthermore, much of the evidence advanced for a relation between a certain factor and the Hearing Threshold Levels is based on the assumption that the workers with the most hearing loss were necessarily the most susceptible, whereas they could well have been merely the most highly-exposed.

(7) Can this susceptibility be changed by drugs or diet? A vast amount of effort has been devoted to study of this area, which we like to call "vulnerability". Although there are many substances (minerals, vitamins) a deficiency in which can affect vulnerability, an excess fails to decrease it. Certain ototoxic drugs act synergistically with noise, as does carbon monoxide. Very few substances decrease vulnerability; the major contender as an ameliorative agent at this time is oxygen, either pure or as the major component of carbogen.

(8) What is the evidence for and against the microtrauma theory as opposed to the critical-incident hypothesis in the production of TTS? Comparatively little study has been made of this question, as it obviously involves monitoring the hearing of a group of people for a long time. We have recently shown that the critical incident theory may be correct after all, despite a widespread belief in the microtrauma scheme. PTS was measured in our chinchillas after one week of exposure 8 h/day to 105-dB noise, after an additional three weeks of exposure, and finally after another 5 weeks of exposure. The PTSs were the same after 1 week as after the total 9 weeks of cumulative exposure, which implies that these animals, whose exposure was rigidly controlled, suffered all their loss in sensitivity during that first week. It can be argued, then, that workers also suffer all their loss in the first few weeks of employment--or that they would do so if their daily exposures were really constant and if there was no contribution to exposure outside the work situation; however, if a severe sociacusic exposure (such as attending a rock concert) increased the total exposure to a value a few decibels greater in L_{eq} than before, additional damage would occur on that day, whereupon the threshold would remain constant until a new highest-ever exposure occurred. Of course, this speculation depends on the validity of extending results on the chinchilla to man, and there are good reasons to challenge such extrapolation, including the fact that the chinchilla always displays delayed recovery from even low values of TTS, a phenomenon ordinarily seen in man only when high values of TTS are developed. Only by carefully following the hearing of a large number of people over a period of many years can we ever hope to settle the question of microtrauma vs. macrotrauma.

(9) To what extent does it make any sense to speak of a "critical intensity" or even a "critical exposure" for a given ear? Critical level, no, but critical exposure, yes. As one increases intensity holding duration constant, a point is reached at which massive destruction takes place. However, the same is true if duration is increased while level is held constant. Level is more important than duration, though; in the chinchilla, the critical exposure appears to depend not on the energy It but rather on I^2t.

(10) Is a damaged ear more susceptible to further damage than a nondamaged one? The secondary question here, but one that must be answered first, is what constitutes equal further damage in a damaged ear vis-a-vis that in a normal ear? If by "equal further damage" one means an equal number of decibels of change in sensitivity, then the damaged ear is <u>less</u> susceptible; otherwise if the first

if the first week of exposure produced a 10-dB loss, so would the second week, and the third, and so on, so that by the end of a year the worker would be stone deaf. It has been shown that damaging one place on the basilar membrane has no effect on the susceptibility or vulnerability of another place, however.

(11) Is some aspect of the TTS produced in a group of listeners a valid index of average expected PTS after years of exposure to that noise? I remain convinced that TTS is the best average predictor we have: an exposure that produces more average TTS than another will almost always produce more PTS as well. TTS has fallen into disrepute, as it were, because it is only a poor predictor of individual differences in susceptibility, but this is not a fatal characteristic if TTS and PTS are both the results of some other underlying mechanism.

(12) If so, which parameter--initial TTS, recovery time, or what? This question has not been addressed, to my knowledge; it is generally assumed that initial TTS is the important parameter.

(13)To what extent is the auditory hazard from noise enhanced by other noxious influences such as vibration, fumes, exertion? This question has already been partially addressed. However, for the specific agents in the question, evidence is only equivocal that vibration enhances NIPTS; exertion does not, and the effect of fumes on hearing directly is generally small if existent at all.

(14) To what extent does intermittence reduce the hazard from a given (cumulative) noise exposure? Well, 20 years of work with the chinchilla has shown conclusively that intermittence does reduce hazard of PTS, though not as much as it reduces TTS. Unfortunately, we have not yet been able to express the ameliorative effect of intermittence in a simple formula, and perhaps we never shall. I do hope, however, that some reasonable way to correct the prediction of damage assuming the equal-energy theory to be true can be found.

(15) In recoverying from TTS, what noise level consitutes "effective quiet"? A hot topic 20 years ago, this topic has not received much attention since. Various experimenters agreed that this level is somewhere around 70 dB, depending on the specific frequency range involved.

(16) Is 4000 Hz the place to first look for auditory damage, or are the very-high frequencies more susceptible? The notion that damage might first appear in the 12-20-kHz range has been subjected to intense scrutiny by many investigators, but no substantial evidence for the theory has ever materialized. Monitoring these ultrahigh frequencies is important for persons taking ototoxic drugs, but serves no purpose in trying to detect beginning hearing loss before it shows up at 4 or 6 kHz.

(17) Does infrasonic noise or ultrasound at commonly-found intensities pose a hazard to health? Not to hearing, at any rate. True, if the head is immersed in an ultrasonic bath of sufficient strength, the highest-frequency receptors in the ear are stimulated, and can be damaged if the level rises further.

What should be our goals for the next 25 years? (1) continue to look for a better descriptor for "exposure" than L_{eq}; (2) institute and maintain a long-term study of the hearing of a random sample of the population; (3) continue to try to determine the effects of intermittence; (4) try to nullify the efforts of anti-noise activists who exaggerate the true hazards of the sounds of everyday life.

RESULTATS DES RECHERCHES MENEES DEPUIS 25 ANS DANS LE DOMAINE DES PERTES AUDITIVES DUES AU BRUIT

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A l'époque de la première conférence sur "Le bruit comme risque pour la santé publique" (le terme "risque" a été remplacé par "problème" lors de la 2ème conférence), nous savions déjà pas mal de choses sur les effets du bruit sur l'audition - ou plutôt, nous étions conscients de ne pas en savoir beaucoup. J'avais résumé la situation comme suit : "Les bruits constants supérieurs à 80 dB A sont capables de provoquer des modifications du seuil d'audibilité, et au dessus de 105 dB (A), ils provoquent à coup sûr une PTS, dans une oreille normale, non protégée, si l'exposition au bruit se poursuit pendant plusieurs années à raison de 8 heures par jour. Nous ne pouvons pas réduire le NIPTS, excepté en réduisant l'exposition au bruit, et il n'y a aucun moyen de la réparer. Bien plus, on est incapable d'identifier l'individu sensible au bruit. Par conséquent, les contrôles audiométriques à l'embauche, et pendant la durée du travail, accompagnés d'un programme de protection de l'audition, sont les seules solutions actuellement disponibles."

Ainsi que nous le verrons, beaucoup de ces affirmations quelque peu pessimistes sont encore vraies aujourd'hui.

Toutefois, avant de tenter de résumer les progrès scientifiques réalisés au cours des 25 dernières années, il faut rappeler les aspects pratiques de notre objectif à tous : éliminer, ou au moins réduire, les pertes auditives dues au bruit dans notre société. En 1968, nous venions tout juste de démarrer des programmes de limitation de l'exposition au bruit sur les lieux de travail, mais il était déjà clair que les bruits de la vie quotidienne étaient souvent plus dangereux que les bruits industriels.

Bien qu'il fût possible de limiter l'exposition des travailleurs par la réglementation, il était nécessaire d'étudier d'autres méthodes pour persuader le citoyen moyen de protéger son oreille, soit en évitant les bruits excessifs, soit en portant des protecteurs individuels.

Tout programme d'éducation du grand public sur les risques du bruit devait surmonter des idées reçues largement répandues. La plus dangereuse est certainement que le risque dépend uniquement du niveau et non pas de la durée. Vous vous rappelez sans doute que le très sérieux Congrès américain avait mandaté l'Agence pour la Protection de l'Environnement, pour fixer, dans la loi sur la lutte contre le bruit (Noise Control Act), les niveaux à atteindre et à maintenir pour protéger la santé publique et le bien être avec une marge de sécurité adéquate.

Ainsi, l'un des problèmes était de faire comprendre à ceux qui allaient rédiger les réglementations que l'exposition à des niveaux sonores élevés est sans danger si la durée est suffisamment courte. Par ailleurs, l'homme de la rue pense que si un bruit n'est pas inconfortable à l'oreille il ne présente aucun danger, quelle que soit la durée d'exposition.

Ainsi nous avons des objectifs quelque peu contradictoires : convaincre le législateur de moins se préoccuper des niveaux, et en même temps persuader chacun de se préoccuper plus de la durée d'exposition.

Je ne suis pas sûr que nous ayons parfaitement réussi dans cette tâche, mais des progrès ont certainement été réalisés. Les protecteurs individuels sont maintenant beaucoup mieux acceptés socialement qu'en 1968 : les bouchons ou les casques sont portés sans protestation, pas seulement par les utilisateurs de marteaux piqueurs mais par beaucoup de particuliers lorsqu'ils tondent leur pelouse, coupent leurs arbres avec une tronçonneuse ou, à l'occasion,

lorsqu'ils utilisent un scooter des neiges, bien que ce dernier exemple puisse impliquer une attitude virile du genre : " Je peux le supporter ". Les derniers vestiges de cette attitude n'ont d'ailleurs pas totalement disparu dans l'industrie, mais sont certainement moins prévalents qu'il y a 25 ans.

Un domaine où le succès a été encore plus grand est celui du tir. Personne ne songerait à participer à une compétition de tir sans protecteurs auditifs. Bien sûr, cela n'est pas dû a nos enseignements - nous aimerions penser qu'ils y ont contribué - mais plutôt à un heureux hasard qui fait que lorsqu'on porte un casque, cela supprime le réflexe de sursaut et améliore donc les performances. Rien ne vaut un bon argument secondaire.

Cela ne veut pas dire qu'il ne reste pas des domaines où les problèmes semblent insolubles. Le plus vaste est celui de la musique. Nos jeunes gens - beaucoup d'entre eux du moins - souhaitent écouter de la musique à un niveau suffisant pour éveiller une réponse viscérale : ils veulent "ressentir" la musique. C'est ainsi qu'ils poussent leur balladeur aussi fort que possible, qu'ils réclament des niveaux de 115 dB (A) et plus dans les concerts et équipent leur voiture d'autoradios hyperpuissants.

Cela ne sert à rien, selon moi, de leur dire qu'ils éprouveront toujours les mêmes sensations en écoutant la musique à haut niveau à travers des bouchons d'oreille.
On n'améliore pas non plus la situation en exagérant dans la presse populaire les dégats engendrés par une exposition à des musiques fortement amplifiées, en se lamentant sur le fait qu'un chanteur rock connu est devenu sourd et que c'est ce qui arrivera à tous ceux qui s'exposent, même occasionnellement, à des niveaux de 115 dB (A). Une fois de plus, cela illustre la confusion qui découle du fait qu'on ne tient pas compte de la durée d'exposition lorsqu'on parle des effets des bruits de forte intensité.

Tout ceci est un exemple du phénomène de surenchère qui prévaut dans notre société : si quelque chose est mauvais pour vous à haute dose, les médias diffusent immédiatement l'idée que de petites doses sont également dangereuses (malheureusement, il y a des "scientifiques" qui font la même chose mais j'espère que nous ne comptons pas d'individus de cette sorte parmi nous !). Ainsi, par exemple, si la cigarette conduit souvent à un cancer du poumon, on devrait empêcher toute la population de respirer dans l'environnement la moindre fumée, même très diluée.
Et à l'occasion, on peut susciter une hystérie collective ainsi qu'en témoigne par exemple la fureur actuelle concernant les prétendus risques des radiations électromagnétiques provenant des lignes électriques, des transformateurs et même des appareils domestiques. On nous mettra sûrement en garde un jour contre les voyages qui nous font passer sur des lignes de flux magnétique et on nous dira que les déplacements excessifs, surtout à grande vitesse, peuvent affecter notre "aura".

L'un dans l'autre, néanmoins, notre domaine ne semble pas trop affecté par ce genre de charabia et d'évidences, bien que des excès apparaissent de temps à autre. Ainsi, de nombreux chefs d'entreprises ne veulent pas se donner la peine de calculer si leurs travailleurs sont ou non surexposés au bruit. Aussi établissent-ils simplement des "zones de bruit" - habituellement tout endroit présentant un niveau de 90 dB(A) ou plus - en exigeant de chacun de porter une protection auditive en entrant dans cette zone, ne serait-ce que pour quelques secondes. Une fois de plus le principe de base du problème bruit/audition est impliqué, à savoir que la durée du bruit n'est pas considérée comme élément essentiel de la dose de bruit.

Cet oubli pernicieux du facteur temps dans l'évaluation du risque vient peut être du fait que ce facteur n'a pas la même importance dans tous les domaines de la pollution sonore, et notamment dans celui de la gêne. Le chien du voisin peut être aussi gênant dès son premier aboiement qu'après cinq minutes de vocalises incessantes. Je suis persuadé que c'est cette dimension de la gêne qui a conduit les auteurs du Noise Control Act à ignorer totalement la notion de durée.

Mais revenons à notre sujet, à savoir les progrès enregistrés d'un point de vue scientifique,

dans le domaine de la surdité due au bruit : jusqu'à quel point avons-nous progressé dans la connaissance, la prévision, le contrôle et la réduction. Au second congrès, celui de Dubrovnik, j'ai posé une série de questions qui, je l'espérais, trouveraient une réponse. Laissez-moi les reposer ici et faire à chaque fois un bref commentaire sur l'état actuel de la recherche.

1. Peut-il y avoir des dommages sur l'audition sans modification de la sensibilité?

Quelques décennies de recherche sur ce sujet n'ont rien apporté de plus que des résultats "prometteurs". Il est vrai que dans une oreille présentant une perte de sensibilité, il y a des phénomènes conjoints, tels qu'une détérioration de la sélectivité des fréquences, mais on n'a pas encore démontré que c'était l'exposition au bruit qui produisait ces changements, de nature permanente, si le seuil de sensibilité est totalement récupéré.

2. Quelle est l'exposition unique (8 heures ou moins) susceptible de produire une PTS significative?

Nous ne savons toujours pas quel est ce seuil dans le cas de l'oreille humaine, le problème ne pouvant être étudié expérimentalement que sur des animaux de laboratoire. 138 dB pendant quelques secondes peuvent provoquer une perte significative chez quelques individus extrêmement sensibles, mais 153 dB pendant 0,4 seconde n'entrainent qu'une fatigue auditive TTS très modérée, de même qu'un bruit de jet de 135 dB pendant une minute.

Chez le chinchilla, le seuil à partir duquel on constate des dommages semble correspondre à l'énergie acoustique d'une exposition de 8 h à 90 dB (A).

3. Quelle exposition relativement constante, de 8 h par jour, pendant plusieurs années, produira une PTS excédant celle que l'on peut attribuer à la presbyacousie associée à la socioacousie ?

Les données sont relativement équivoques et fixent ce niveau à 80 dB (A) chez l'homme, bien que certains prétendent encore que cette "limite" soit de 75 dB (A).

Ils oublient que l'effet qu'ils étudient est le résultat conjoint du bruit au travail et des bruits de la vie quotidienne.

4. Existe-t-il un moyen de corriger les données audiométriques concernant la presbyacousie associée à la socioacousie, autre que la simple (et probablement erronée) soustraction?

Nous travaillons encore à l'heure actuelle sur ce problème important mais probablement insoluble. Une correction basée sur le cumul semble devoir fonctionner même si les bruits industriels et les bruits de loisirs doivent affecter les mêmes éléments dans le mécanisme de l'audition; auquel cas on ne peut s'attendre au cumul des effets mais seulement au cumul de l'effectiveness.

5. Dans quelles conditions l'hypothèse de l'énergie équivalente est-elle valable pour une exposition continue ? Chez le chinchilla au moins pour une exposition unique ininterrompue.

Ceci était une question très orientée car à l'époque nous travaillions justement sur le sujet. Il s'est avéré que ceci était vrai non seulement pour des expositions uniques ininterrompues mais aussi pour des expositions quotidiennes ininterrompues. Ce n'est que lorsque l'exposition journalière est intermittente que la théorie de l'énergie équivalente ne fonctionne

plus.

6. Peut-on prévoir les différences individuelles de sensibilité ? Après une multitude d'études, la réponse est encore : "pas très bien ".

La PTS, à certaines fréquences est correlée de manière significative à la TTS et la TTS consécuti[illegible] bruit de spectre donné, peut permettre de prévoir une PTS pour des expositions plus sévè[illegible] ce même bruit. Les études semblent indiquer également que la sensibilité dépend, de la couleur des yeux, du sexe, et d'autres caractéristiques de l'individu mais la valeur prédictive n'est que faible. De plus, beaucoup des faits avancés pour démontrer la relation entre un facteur donné et les seuils d'audition sont basés sur l'hypothèse que les ouvriers présentant la plus forte perte d'audition sont les plus sensibles, alors qu'il se pourrait qu'ils soient plutôt les plus exposés.

7. Cette sensibilité peut-elle être modifiée par des médicaments ou par un régime alimentaire ?

Beaucoup d'efforts ont été déployés pour explorer ce domaine, que l'on pourrait désigner par le terme "vulnérabilité". Bien qu'une carence en certains minéraux et vitamines puisse provoquer une déficience auditive, un excès de ces éléments n'entraine pas une amélioration. Certains médicaments ototoxiques agissent en synergie avec le bruit, comme le monoxyde de carbone. Très peu de substances diminuent la vulnérabilité ; à l'heure actuelle l'agent le plus performant est l'oxygène, soit pur, soit comme élément majeur du carbogène.

8. Quels sont les arguments pour et contre la théorie du microtrauma, opposée à l'hypothèse de l'incident critique dès l'apparition de la TTS ?

Peu d'études ont été faites sur ce sujet et cela implique de surveiller l'audition d'une population sur une longue période de temps. Nous avons démontré récemment que la théorie de l'incident critique peut être correcte, malgré une croyance très répandue du microtrauma.

La PTS a été mesurée sur des chinchillas après une exposition d'une semaine, 8 h par jour, à un niveau sonore de 105 dB, puis après 3 semaines supplémentaires d'exposition et enfin, après 5 semaines d'exposition. Les PTS étaient les mêmes après une semaine qu'après 9 semaines d'exposition cumulée, ce qui implique que ces animaux, dont l'exposition a été strictement contrôlée, ont subi leur perte de sensibilité au cours de la première semaine. On peut dès lors supposer que les travailleurs perdent également leur auditon dans les premières semaines suivant leur embauche, ou que du moins cela serait ainsi si leur expostion journalière était rigoureusement constante et s'ils n'étaient pas exposés au bruit à l'extérieur de leur lieu de travail. Toutefois, si une exposition sévère lors de la vie extra professionnelle (telle que lors d'un concert rock) venait à augmenter l'exposition totale de quelques décibels en Leq, un dommage supplémentaire apparaitrait ce jour là, après quoi le seuil demeurerait constant jusqu'à une nouvelle exposition à niveau encore plus élevé.

Bien sûr, ces spéculations reposent sur la validité de l'extrapolation à l'homme, des résultats observés sur le chinchilla, et il y a de bonnes raisons de relever ce défi.
comme le fait, par exemple, que le chinchilla présente toujours un temps de récupération très long même pour des faibles valeurs de TTS, ce qui n'est observé chez l'homme que pour des valeurs élevées de TTS.

Ce n'est qu'en suivant avec soin l'audition d'un large échantillon de population pendant plusieurs années que l'on pourra espérer répondre définitivement à la question "microtrauma contre macrotrauma".

9. Jusqu'à quel point peut-on parler "d'intensité critique" ou même "d'exposition critique" pour une oreille donnée ?

Niveau critique, non, mais exposition critique, oui. Lorsqu'on augmente l'intensité en maintenant la durée constante, on atteint un point de destruction massive. Toutefois, cela est vrai aussi lorsqu'on augmente la durée en maintenant le niveau constant.

Le niveau est pourtant plus important que la durée. Pour le chinchilla, l'exposition critique semple dépendre non pas sur l'énergie It mais plutôt sur I^2t.

10. Une oreille endommagée est-elle plus susceptible d'être encore davantage endommagée qu'une oreille saine ?

La question secondaire, mais à laquelle il faut répondre en premier, est : qu'est-ce-qui constitue un dommage futur équivalent pour une oreille endommagée par rapport à une oreille normale ?

Si, par dommage futur équivalent, on entend nombre égal de décibels dans la perte de sensibilité, alors on peut dire que l'oreille endommagée est moins sensible ; sinon, si la première semaine d'exposition provoque une perte de 10 dB, la deuxième semaine devrait provoquer la même chose, de même que la troisième et ainsi de suite, si bien qu'à la fin , le travailleur serait totalement sourd. Il a été démontré que si un endroit de la membrane basilaire est abimé, cela n'a pas de conséquence sur la sensibilité ou la vulnérabilité d'un autre endroit.

11. La TTS produite dans un groupe d'auditeurs est-elle un indicateur de la PTS moyenne prévisible après plusieurs années d'exposition à ce bruit ?

Je reste convaincu que la TTS est le meilleur indice prévisionnel que nous possédions : une exposition qui entraine plus de TTS qu'une autre entrainera presque toujours plus de PTS également.

Il semble que la TTS soit tombée en disgrâce, car c'est un indicateur médiocre des différences individuelles de sensibilité au bruit, mais cela n'est par une caractéristique capitale si TTS et PTS sont toutes deux le résultat d'autres mécanismes sous-jacents.

12. S'il en est ainsi, quel paramètre : la TTS initiale, le temps de récupération ou autre chose?

Cette question n'a pas été posée, du moins à ma connaissance. On prétend généralement que la TTS initiale est le paramètre important.

13. Jusqu'à quel point le risque auditif dû au bruit est-il renforcé par d'autres influences nocives telles que les vibrations, les fumées, les efforts?

Cette question a déjà été partiellement posée. Toutefois, en ce qui concerne les agents spécifiques en question, il est évident que les vibrations renforcent le NIPTS, ce n'est pas le cas des efforts et les effets directs de la fumée sur l'audition sont faibles, si ce n'est même inexistants.

14. Dans quelle mesure l'intermittence réduit-elle le risque d'une exposition au bruit ?

Et bien, 20 ans de recherches sur le chinchilla ont démontré de façon concluante que

l'intermittence réduit le risque de PTS, moins cependant qu'elle ne réduit le risque de TTS. Malheureusement, nous n'avons pas été capables jusqu'à présent d'exprimer cette amélioration par une formule simple et peut-être n'en serons nous jamais capables. J'espère toutefois qu'on trouvera un moyen raisonnable de corriger la prévision du risque en démontrant que la théorie de l'énergie équivalente est juste.

15. Au cours de la période de récupération, quel niveau sonore constitue effectivement le calme ?

C'était un sujet chaud il y a 20 ans, mais il n'a pas trouvé beaucoup d'écho depuis.. Différents spécialistes s'accordent à dire que ce niveau est voisin de 70 dB et qu'il dépend de la fréquence considérée.

16. Faut-il étudier la fréquence 4000 Hz comme premier indicateur de la perte auditive, ou bien les très hautes fréquences sont-elles plus significatives ?

L'hypothèse que le dommage pourrait apparaître d'abord dans les fréquences 12 000 - 20 000 Hz a été étudiée par de nombreux chercheurs, mais aucune certitude n'a pu être dégagée.

Il est important de contrôler ces fréquences chez les personnes prenant des médicaments ototoxiques mais cela ne sert pas à détecter un début de perte auditive avant qu'elle ne s'installe dans les 4000 ou les 6000 Hz.

17. Les infrasons et les ultrasons, à des intensités existant de façon courante, présentent-ils un risque pour la santé ?

Pas pour l'audition, en tous les cas. Certes, si la tête est immergée dans un bain ultrasonique d'intensité suffisante, les récepteurs des hautes fréquences de l'oreille sont stimulés et peuvent être endommagés si le niveau augmente encore.

<u>Quels devraient-être nos objectifs pour les 25 années à venir ?</u>

- Continuer à rechercher un indicateur de l'exposition au bruit plus satisfaisant que le Leq ;

- Mettre en place une surveillance régulière, à long terme, de l'audition d'un échantillon de la population ;

- Poursuivre les recherches sur les effets de l'intermittence ;

- Tenter de contrecarrer les efforts des activistes de la lutte contre le bruit qui exagèrent les conséquences que peuvent avoir sur la santé les bruits de la vie quotidienne.

TTS : temporary threshold shift : élévation temporaire du seuil auditif
PTS : permanent threshold shift : élévation permanente du seuil auditif
Leq : niveau énergétique équivalent

PSYCHOLOGICAL FACTORS OF COMMUNITY REATION TO NOISE

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INTRODUCTION

The British Navy introduced citrus fruit as part of the regular diet of sailors over 160 years after the discovery (in 1601) that citrus juice cures scurvy. It took another 70 years before scurvy was wiped out of the merchant marine: a total lag from discovery to implementation of 264 years. Even today it has been estimated that the lag from relevant psychological discovery to implementation in westernized educational systems is around 30 - 40 years. By comparison, the speedy and successful impact of the noise research is surprising.

The reactions to noise of humans living in residential communities near noise sources has been under investigation for over 30 years. In some respects this research has been quite successful. The curve relating noise exposure to the extent of community reaction (Schultz, 1978), although not uniformly agreed upon, appears valuable within reasonable error bands. Furthermore, from a practical point of view, this research has formed the basis of public policy in a large number of countries. This has resulted in an impressive list of countermeasures to reduce residential exposure to noise, including noise barriers on roads, insulation of homes at the expense of government bodies, noise sensitive land use planning, noise insulation and visual isolation of stationary noise sources, more stringent noise emission standards in aircraft and other machinery, rearranged firing times at artillery and rifle ranges and night time curfews at some airports.

However, at a pure rather than applied level, when individual rather than group data are considered the achievements have not been so strong. The extent to which individual reaction to noise can be predicted from noise exposure is notoriously low. This paper addresses the extent to which individual reaction is accounted for by noise exposure and psychological variables in socioacoustic surveys, and points to a number of ways in which individuals' reactions to noise may be better understood and better researched.

THE IMPORTANCE OF INDIVIDUAL REACTION

It may be argued that, given the successes of this research field in terms of practical, social and political outcomes and a broad predictability of group data, the issue of wide variation in individual reaction is unimportant. There are a number of reasons for considering the issue worthy of our research endeavour.

First, there is the pure science approach, that an understanding of human reaction to noise is inherently valuable Such an understanding may also provide a piece of the puzzle in nearby research fields. Second, our complacency with our knowledge may not be well justified. Research into the as yet unknown may reveal errors in what is currently "known". In particular, this may be the case with the common restriction of measuring subjective annoyance as the sole component of community reaction. Third, as yet undiscovered variables or

relationships may themselves have important practical implications. Pure research has a habit, in the long term, of producing a better practical solution than that coming from applied research. It was pointed out that the applied research answer to polio was to find the most efficient, most mobile iron lung. However, what started out as pure research into the causes of polio produced a greatly superior solution: a vaccine.

ACCOUNTING FOR INDIVIDUAL REACTION

The fact that only a small proportion of the variation in individual reaction is predictable from noise exposure (typically around 9% to 29 %, based on a mean correlation of .42+/- .12, compared with over 60 % for group data: Job,1988) is not in itself a cause for concern. There are many other variables which could contribute to the account of reaction. Most are psychological. Indeed it would be unusual if psychological factors were not important. Noise, as distinct from music or speech or sound, contains psychological components by definition: noise may be seen as unwanted sound (Stansfeld,1992, p3), and the determination of whether or not a sound is wanted is a psychological matter.

A few attempts have been made to determine how much individual reaction is left unaccounted for. For example, Bullen, Hede and Kyriacos (1986) conducted regression analysis against reaction and accounted for 59.4% of the variation using modifying variables (attitude, noise sensitivity etc.). Noise exposure accounted for 13%. However even small correlations between noise exposure and some modifying variables mean that these percentages can not be added to yield a total percentage explained. A further 13.3% of the variation appears to be error in the measurement of reaction. This leaves probably around 20% unaccounted for. Similarly, Hede and Bullen (1982) reported that multiple regression revealed that 65.5% of the variation in reaction is accounted for by sensitivity, attitude and noise exposure. When the amount of error in the reaction measure itself and the other variables are considered, less than 20% of the variance is left to be accounted for. While there is some evidence (e.g. McKennell,1978) to support the assumption that the modifying variables are true modifiers of reaction rather than components of reaction or are themselves influenced by reaction, the issue is not settled. Indeed, Bullen et al. (1986) produced some evidence themselves that attitude is not a pure modifying factor. On this argument, it might reasonably be suggested that at least one third of the variation in reaction remains to be accounted for.

A regression analysis on the data collected by Job and Hede (1989) on reaction to power station noise supports the suggestion that a substantial proportion of the variance in reaction is not yet accounted for. The variables used in the regression included noise exposure, three scales of attitude, two scales of noise sensitivity, occupation, education, home ownership, age, years living in the area, visibility of the power station and reported reaction to fumes from the (coal burning) power stations. With all these variables allowed to enter the predictive equation, only 40% of the variation in general reaction was accounted for. Allowing for the possibility that perhaps as much as 36% of the variation in reaction is error variance, this still leaves 24% unexplained.

The importance of the psychological variables is evidenced by their role in these regressions. The use of regression analysis, of course, takes account of any relationship between noise exposure and the modifying variables. The results lend strong statistical support to the evidence for correlations between attitude and reaction, and between noise sensitivity and reaction, independent of noise exposure (Fields, 1992; Job,1988). The analysis by Bullen et al. revealed greater potential account of reaction by noise sensitivity and by negative attitudes towards the noise source than by noise exposure. The regression analysis on the data from Job and Hede (1989) resulted in a number of variables which significantly predicted reaction. In order of impact these were negative attitudes regarding the authorities at the power stations, attitudes towards the physical consequences of the stations, noise exposure, general noise sensitivity, neighbour noise sensitivity (to lawn mowers, etc.) and attitudes towards the usefulness of the power stations. This pattern of regression results supports Fields' conclusion from an extensive review, that attitudinal (and sensitivity) factors are important in predicting reaction, whereas demographic factors (age, home ownership, etc.) are not. These regression analyses also suggest that on average over 50% of the variation in reaction is accounted for by psychological factors measured in the surveys, which is considerably more than is accounted for by noise.

While the relevance of a number of psychological variables in human response to noise is recognized, the possibility remains that there are a number yet to be established.(Although it may indeed be the case that nothing is uncovered in the recommended research this in itself is valuable information). However the current research field presents a number of barriers to a fruitful search. Six such barriers are identified and discussed below.

1. Annoyance as Reaction

In addition to the possible more physical effects of noise, and psychological/psychiatric effects (Kryter, 1991; Stansfeld, 1992), subjective community reaction consists of more than just annoyance.

Socioacoustic investigations almost uniformly employ annoyance as the measure of community reaction, as evidenced by Schultz' use of annoyance as the measure in his synthesis. Fear is also sometimes measured as reaction, or sometimes as a modifying variable (see Fields, 1992) and sleep loss is also studied. However subjective reaction may be much more than, or even different from, annoyance. People may react with anger, disappointment, withdrawal, feelings of helplessness, depression, anxiety, distraction, agitation or exhaustion. In a report deserving wider circulation, Hede, Bullen & Rose (1979) described a study of the words used by people to describe their reactions to various noises. The data showed that many words used did not correspond to annoyance. Further, they demonstrated that the word "affected" tapped more reaction than the word "annoyed". The partial correlation between "affectedness" and noise exposure was 0.25 at constant annoyance, rather than the zero correlation expected if annoyance were the only component of reaction. It would seem better not to specify an emotion in at least one question, so that unspecified negative emotions may be detected. For example, the extent of effect, or the extent of

dissatisfaction have been used effectively (Bullen and Hede, 1982; Job & Hede, 1989).

The assumption that annoyance provides full coverage of subjective reaction is in need of revision.

2. Methodological Issues.

There are a number of well recognized methodological concerns of particular relevance to the present research field. There is no need to recount the problems of subject self selection of noise exposure and the difficulties in establishing causality, which arise from the cross-sectional methodology common to the field. Other social survey issues relevant to noise reaction have also been examined (see Job & Bullen, 1987).

However, two methodological problems in the measurement of psychological variables continue to have a detrimental impact on socioacoustic research. First, the use of a single question to measure reaction is inadequate. This is established to produce a less reliable measure than the use of several questions combined to produce a scale (see Job, 1988, 1991). Furthermore, the use of a single question measure does not allow an estimate of the internal consistency of reaction.

Second, while we have relatively standard questions for noise sensitivity (e.g. Weinstein, 1980) and reaction, the measurement of attitude towards the noise source remains unstandardised, and varies greatly from study to study. Even when a number of questions are employed on attitude common questions are rare. (Our own work demonstrates this unfortunate feature: comparing the scales employed by Bullen, Hede and Kyriacos, 1986, and Bullen, Hede and Job, 1991, revealed only two reasonably comparable questions out of a possible ten). Nonetheless a synthesis of the questions employed in a variety of surveys of artillery, aircraft, rifle ranges and power stations, along with the attitudes identified as important in Field's (1992) review, suggests that a standard measure of attitude is possible even for quite different noise sources. Such a scale is proposed in Table 1. The use of a standard scale would allow much greater comparability of surveys and a comprehensive measure of the various components of attitude towards a noise source. With the responses scored from 1=strongly disagree to 5=strongly agree, five scales of attitude are produced by the proposed set of questions. The scales and scoring are:

Attitude 1 (Not enough is being done)= (q5 + q12 -q1 -q8 +12)/4
Attitude2 (Danger)= (q2 -q9 -6)/2
Attitude3 (Lack of function)= (q6 -q3 -q10 -q13 +18)/4
Attitude4 (Alternatives)= q11
Attitude5 (Other physical effects)= (q4 -q7 +6)/2

The above scoring includes rescaling so that a score on any scale represents the average level of agreement (scaled 1 to 5) with a negatively worded attitudinal statement.

Table 1: A Standard Questionnaire on Attitudes to a Noise Source

We are interested in your opinions about _________(name of noise source). Please tell me whether you -
Strongly agree, agree, have no opinion, disagree, or strongly disagree with each of the following statements:

1. Authorities at _______do their best to reduce the noise.

2. ________ is a danger in the area.

3. ________ is of value to the area.

4. _________ is visually attractive in the area.

5. The government is not doing enough to stop noise pollution.

6. ________ is a waste of money.

7. _________ creates air pollution in the area.

8. The (workers, pilots, shooters, drivers) at ______ are concerned about the noise they make.

9. ________ poses no threat to safety.

10. ________ serves an important function.

11. There are better alternatives than using _______.

12. A lot more could be done to stop the noise from _____.

13. ________ provides valuable (specify: employment, training, defense, product, other).

3. Certain predictors of noise may be differentially effective as predictors of certain reactions.

One consequence of a combined or single question measure of reaction is that the possibility that certain predictors are differentially powerful in predicting certain reactions but not other reactions, is left unexamined. One *prima face* example is that night time noise may be a better predictor of sleep disturbance than is daytime noise, whereas daytime noise may be the better predictor of disturbance with outdoor activities. The possibility that a number of such relationships exists should be allowed investigation. A number of possibilities are predicted by relevant data and theory. These include (among many other possibilities): Noise sensitivity may be a differentially effective predictor of psychiatric disturbance, although the causal sequence is not entirely clear (Stansfeld, 1992). The extent of subjective or objective uncontrollability and unpredictability of the noise may be differentially effective predictors of stress reactions, or depression. Unpredictability and uncontrollability may also relate to circulatory health in that uncontrollable/unpredictable shock increases cholesterol levels in laboratory animals, even in the absence of significant dietary cholesterol intake (Brennan et al., 1992). Note that these variables do vary: Some people are, at least partially, able to control their noise exposure through closing windows, using air-conditioning, or moving rooms. Some see their noise exposure as controllable or predictable while others do not. Some noises are more predictable (traffic noise is reliably greater at certain times of the day and on certain days; slow onset noises have a predictable peak and may be seen as more predictable than impulsive noise). The latter observation may be relevant to the well documented finding that reaction is greater for impulsive noises than for non-impulsive noises of the same loudness.

4. Unclear Direction of Causality.

One consequence of the cross-sectional method common in socioacoustic research is that the correlations observed are silent as to the direction of causality. Careful examination of the inter-relationships can be informative (e.g.. McKennell, 1978). Two obvious and valuable alternatives are available: experimental manipulations and longitudinal studies. The call for such studies has been made before (e.g.. Berglund, Berglund & Lindvall, 1984), and such studies are occurring (e.g.. Stansfeld, 1992). Nonetheless, such studies may be expanded beyond their current common forms. One valuable extension is to take experimental methods from the laboratory into the field. For example, more information on the causal role of attitudes could be obtained by manipulating attitude in respondents (with an unmanipulated control group) prior to surveying. Such manipulations of attitude are possible through written or verbal means. Noise exposure (and attitude) are also manipulated by public noise attenuation measures. More or less effective insulation, which may nonetheless produce a uniform effect on attitude, would allow comparison of the relative

contributions of noise reduction and improved attitude in accounting for changes in reaction. Finally, having people do specified activities while exposed to controlled noise in the home is manipulation which may shed light on the role of activity at the time of noise exposure in determining level of reaction.

5. Psychological variables deserving greater attention.

While a large number of psychological and demographic variables have been examined in socioacoustic studies (see Fields, 1992), some *prima face* relevant variables have received little attention. Examples follow: Stressors and risk factors other than noise may contribute to reaction. The noise may be the 'last straw' in producing annoyance or dissatisfaction. Perceived or real uncontrollability or unpredictability of the noise may be important variables, with noteworthy theoretical relevance (as identified in the next section). Negativity as a trait is likely to influence reaction, in that more negative evaluations of the noise are likely from people with high negativity. While this deserves more attention, it is not clear as to what extent this factor is inadvertently tapped by negative responses on noise sensitivity or attitudinal scales.

The respondent's common or likely activities at the times of noise exposure may be relevant to reaction. Some activities, such as telephone conversation or sleeping, are more disturbed by noise than other activities such as mowing the lawn. A particularly relevant group for this possibility is shift workers who may be trying to sleep at noisier times. Furthermore, Berglund, Harder & Preis (1991) have evidence which supports this concern with activity at the time of noise: they found that whether or not a person understood the language being spoken was an important factor in thier annoyance with interuptions by noise or silent gaps. While surveys often include questions on whether or not the noise disturbs certain activities, the extent of the persons participation in these activities is not known. It may be misleading to record the same score for two respondents who both say that the noise disturbs reading when one respondents reads for hours every day and the other reads only once in a few months. Clearly, this is a variable needed in future surveys.

6. The Application of Psychological Theory.

While the research field has been successful in applied areas and in mathematical modeling of reaction, human reaction is not well understood at a theoretical level. One reason for the predomination of applied outcomes is the high proportion of research funding based on short term and often local outcomes by government bodies, not uncommonly in response to community complaints. Theory is easily neglected under such circumstances. However, theory should be pursued, and a number of theories in related psychological fields may be fruitfully imported. Three are suggested.

Stansfeld (1992; Stansfeld et al., submitted) observed that in women depression is related to noise sensitivity, and that noise sensitivity remained high after recovery from depression. However, sensitivity did fall somewhat with

recovery from depression. In males, interactions between sensitivity, noise exposure, and psychological morbidity were observed. Finally, noise sensitivity does predict physiological reaction to noise. This pattern of results is suggestive of a failure to 'filter out' or ignore irrelevant stimuli in the psychologically morbid respondents. Such a theory of psychiatric disorder has existed for some time and is relevant to reaction to noise. If those who have a predisposition towards psychiatric illness are less able to ignore irrelevant stimuli (including noise), then exposure to noise is likely to have greater impact on them than on others. This possibility may deserve further investigation.

The other suggested theories both arise from work on laboratory animals and humans exposed to uncontrollable/unpredictable outcomes. The direct relevance of these theories lies in the, at least partially, uncontrollable and unpredictable nature of residential noise exposure. Furthermore, the variability in perceived or real uncontrollability and unpredictability allows investigation of the impact of these variables on the theoretically predicted outcomes. Learned helplessness theory suggests that uncontrollability will lead to cognitive impairment, loss of motivation, emotional changes and even depression (see Maier & Seligman, 1976). Anxiety theory holds that unpredictability rather than uncontrollability is the critical determiner of the effects observed in the relevant experiments, including particularly exaggerated fear and anxiety - known outcomes of noise exposure. Anxiety theory is described along with supporting evidence by Minor et al., 1991).

Finally the common ground of depression as an outcome makes the application of these theories more appealing. Noise exposure and sensitivity have been predictive of psychiatric hospital admissions (Kryter, 1990) and depression in particular (Stansfeld, 1992; Stansfeld et al., submitted). The learned helplessness/anxiety account of certain depressions has yielded an impressive array of parallels between the consequences of exposing animals and humans to uncontrollability/unpredictability and the features of human depression. These common features include:

Removed by anti-depressant drugs, but not by other anti-psychotic drugs.

Removed by ECT (shock therapy).

Produce cognitive impairment.

Produce reduced motor activity.

Results in increased anxiety and fear.

Produce loss of appetite and loss of body weight.

Results in more finicky consumption of bitter/novel tastes.

Are sensitive to the dexamethosone suppression test for depression.

Results in decreased perception of personal control in life.

For reviews addressing the parallels see Dess (1991), Minor et al. (1991) and Overmier & Hellhammer (1988).

One retrospective way to examine the possible role of uncontrollability/unpredictability and helplessness is to examine answers on a related question in previous surveys. In a number of surveys conducted in Australia two common questions occurred. Respondents were asked to report their level of agreement with the statements- The government is not doing enough about/ does not care about noise pollution, and there is no use complaining because no one will do anything about it anyway. The latter question may be seen as an expression of helplessness. It would seem that agreement with the former question should be more relevant and so higher for government (especially defense) managed than civilian run noise sources. The results on this question are presented in the left panel of Figure 1. These results support the proposed difference. The application of these theories would predict that with less controllability, there should be more agreement with the expression of helplessness by residents around the government run noise sources. The available data, presented in the right panel of Figure 1, support this prediction.

The application of learned helplessness and anxiety theories suggests relationships between specific variables: perceived and real levels of controllability and predictability of noise, depression, anxiety, fear, and attributional style (see Abramson, Seligman & Teasdale, 1978). The parallels identified suggest that research on these possibilities is worthwhile, and may account for some of the remaining variance in individual reaction to noise.

CONCLUSIONS

The following conclusions are supported by the above review:

Psychological variables are critical and deserve greater attention

Reaction is much more than annoyance.

Reliability of the measurement of reaction (and other subjective variables) is important.

There are psychological variables left to be explored.

Application of psychological theory is of potential value in uncovering variables which may predict more of the variance in reaction and may help in a theoretical understanding of human reaction to noise.

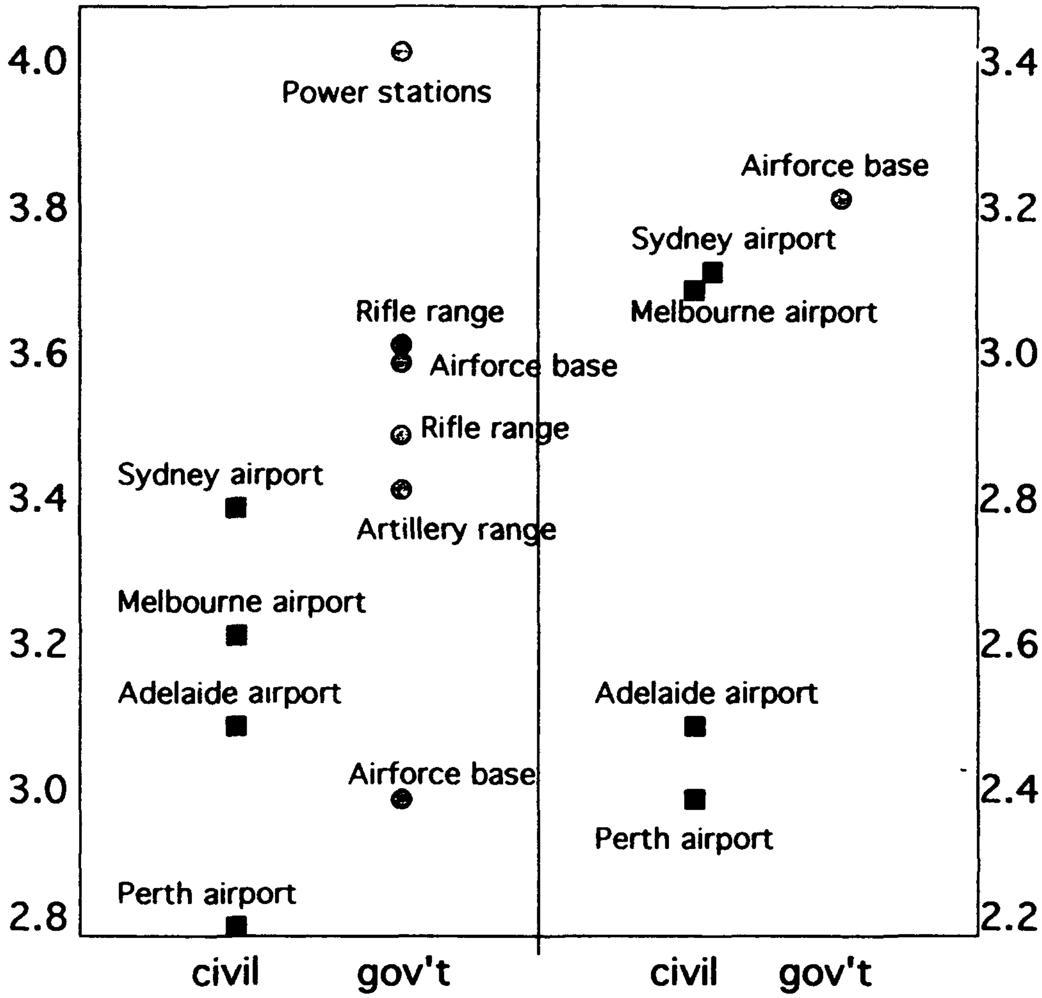

Figure 1: Attitudes to the noise source as a function of civil versus government run noise sources.

The left panel shows agreement (on the scale 5=strongly agree to 1= strongly disagree) for the claim that the government is not doing enough about noise. Results suggest rational differences between civil and government noise sources.

The right panel shows agreement (on the same scale) for the claim that there is no use complaining about the noise because no one will do anything about it anyway. Results suggest more helplessness with gov't noise sources.

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LES FACTEURS PSYCHOLOGIQUES DE LA REACTION DES POPULATIONS AU BRUIT

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INTRODUCTION

La Marine Britannique a introduit les agrumes dans le régime alimentaire des marins 160 ans après que l'on eut découvert (en 1601), que le jus de citron guérissait le scorbut. Il a fallu attendre 70 années de plus avant de voir cette maladie disparaître de la Marine marchande, ce qui fait au total 264 ans entre la découverte et son application. Encore aujourd'hui, on estime que le laps de temps entre une découverte pertinente et sa mise en oeuvre, dans les pays industrialisés occidentaux, est d'environ 30-40 ans. En comparaison, l'impact rapide et efficace des recherches sur le bruit est étonnant.

La réaction des personnes riveraines de sources de bruit est étudiée depuis plus de 30 ans. Sous certains aspects, la recherche s'est révélée assez fructueuse. La courbe liant l'exposition au bruit à la gêne exprimée par les populations (Schultz, 1978), bien qu'elle ne soit pas acceptée par tous semble être valable dans des limites d'erreurs raisonnables. De plus, d'un point de vue pratique, cette recherche a servi de base aux politiques de lutte contre le bruit mises en oeuvre dans de nombreux pays. Cela a débouché sur une liste impressionnante de mesures destinées à réduire le bruit dans les zones d'habitation, incluant par exemple les écrans routiers, l'isolation des bâtiments à la charge des pouvoirs publics, la prise en compte du bruit dans la planification urbaine, l'isolation des sources de bruit fixes, la définition de niveaux de bruit à l'émission de plus en plus sévères pour les avions, les véhicules, les machines, le réaménagement des horaires d'exercice de tir de l'armée, l'instauration de couvre-feux dans certains aéroports.

Toutefois, à un niveau fondamental et non plus appliqué, quand on considère l'individu lui-même plutôt que le groupe social, les progrès n'ont pas été si extraordinaires. Les moyens de prévoir la réaction individuelle au bruit à partir des caractéristiques de l'exposition sont très faibles. Cet article s'attache à examiner dans quelle mesure la réaction individuelle est prise en compte dans l'exposition au bruit et dans les variables psychologiques des enquêtes socioacoustiques. Il met en lumière un certain nombre de pistes pour mieux comprendre et mieux étudier les réactions individuelles au bruit.

L'IMPORTANCE DE LA REACTION INDIVIDUELLE

On pourrait prétendre, compte tenu des succès obtenus dans ce domaine en termes de résultats pratiques, sociaux, politiques et de possibilités de prévoir les réactions de populations, que les variations très grandes enregistrées dans les comportements individuels n'ont aucune importance. Il y a pourtant nombre de raisons pour nous intéresser à ce domaine de recherche.

Tout d'abord, il y a l'approche fondamentale qui fait que la compréhension d'une réaction humaine est intrinsèquement intéressante. Une telle connaissance peut également fournir une pièce du puzzle dans le domaine des recherches voisines. Par ailleurs, notre complaisance vis-à-vis de nos connaissances peut ne pas être tout à fait justifiée. Des recherches dans ce qui est encore inconnu pourraient nous révéler des erreurs dans ce que nous considérons comme connu. En particulier, ce pourrait être le cas pour ce qui est de la prise en compte de la gêne comme seul critère de la réaction des populations au bruit.

Enfin, des variables ou des interrelations encore inconnues pourraient avoir d'importantes implications pratiques. La recherche fondamentale débouche à long terme sur de meilleures solutions pratiques que la recherche appliquée.

On a fait remarquer que la réponse de la recherche appliquée au problème de la polio a été de trouver le poumon artificiel le plus efficace, le plus mobile. Pourtant ce qui a demarré comme une recherche fondamentale sur les causes de la polio a finalement apporté une solution bien supérieure : le vaccin.

LA PRISE EN COMPTE DES REACTIONS INDIVIDUELLES

Le fait qu'une faible proportion seulement des réactions de l'individu puisse être prévisible à partir des données de l'exposition au bruit (entre 9 et 29%, avec un coefficient de corrélation de 0.42 + ou - 0.12, comparé à plus de 60% pour un groupe social donné, Job, 1988) n'est pas en soi un problème. Il y a beaucoup d'autres variables qui pourraient rendre compte de la réaction de l'individu. La plupart sont psychologiques. Il serait d'ailleurs étonnant que les facteurs psychologiques n'aient pas d'importance. Le bruit, qui n'est ni musique, ni parole, ni son, contient par définition des composantes psychologiques : le bruit peut être un son non désiré (Stanfeld, 1992, P. 3) et déterminer si oui ou non un son est désiré est déjà du domaine psychologique.

Quelques tentatives ont été faites pour déterminer dans quelles mesures les réactions individuelles sont laissées pour compte. Par exemple, Bullen, Hede et Kyriacos (1986) ont réalisé une analyse de la courbe de régression des réactions individuelles et ont constaté que 59,4% des variations pouvaient être imputées à des variables modifiantes telles que attitude, sensibilité au bruit, etc... L'exposition au bruit entrait en ligne de compte pour 13%. Toutefois, même de faibles corrélations entre l'exposition et certaines variables inflEantes signifient que ces pourcentages ne peuvent pas être additionnés pour obtenir 100% de réactions expliquées. Un pourcentage supplémentaire de 13% des variations peut être attribué à une erreur de mesure de la gêne. Cela laisse environ 20% non expliqués. De façon similaire, Hede et Bullen (1982) ont montré que 65,5% de la variation enregistrée dans les réactions peuvent être expliqués par la sensibilité, l'attitude et l'exposition au bruit. Lorsque l'on considère le taux d'erreurs dans la mesure de la gêne ainsi que les autres variables, il reste moins de 20% de la variance à expliquer. S'il semble raisonnable (Mc Kennel 1978) de prétendre que les variables sont de véritables modificateurs de la réaction et pas seulement des composantes de la réaction et qu'elles peuvent elles-mêmes être influencées par la réaction, des composantes de la réaction : le résultat n'est pas encore établi. D'ailleurs Bullen et al (1986) ont apporté eux-mêmes des preuves que l'attitude n'est pas un pur facteur de modification. Sur la base de cet argument, on peut raisonnablement suggérer qu'au moins 1/3 des variations dans les réactions des individus doivent encore trouver une explication.

Une analyse de la régression effectuée sur des informations collectées par Job et Hede (1989) concernant la gêne due à une centrale électrique, montre qu'une part importante de la variance n'est pas encore expliquée. Les variables utilisées dans cette étude étaient l'exposition au bruit, 3 échelles d'attitude, 2 échelles de sensibilité au bruit, la profession, le niveau d'éducation, le fait d'être ou non propriétaire de son logement, l'âge, le nombre d'années passées dans cet environnement, la visibilité de la centrale, les réactions aux fumées du charbon brulant dans ces centrales. Avec toutes ces variables entrant dans le modèle de prévision, 40% seulement de la gêne globale peut-être expliquée. Si l'on considère que 36% environ des variations de réactions sont une erreur de la variance, cela laisse encore 24% de réactions inexpliquées.

L'importance des variables psychologiques est bien mise en évidence dans ces analyses de régression. Ces analyses tiennent compte, bien sûr, de toutes les relations entre l'exposition au bruit et les variables influentes. Les résultats ont apporté une solide base statistique à la mise en évidence de corrélations entre attitude et réaction, entre

sensibilité au bruit et réaction indépendantes de l'exposition au bruit (Fields 1992, Job 1988). L'analyse de Bullen et al a révélé un rôle potentiel plus grand dans la réaction de la sensibilité au bruit et d'attitudes négatives que de l'exposition elle-même. L'analyse de régression sur les informations recueillies par Job et Hede (1989) a permis de définir un certain nombre de variables qui peuvent prédire de manière significative une réaction au bruit.
Par ordre d'importance, ce sont :
- attitude négatives concernant les responsables de la centrale ;
- attitude vis-à-vis des conséquences physiques de la station ;
- exposition au bruit ;
- sensibilité au bruit en général ;
- sensibilité au bruit de voisinage (tondeuse à gazon, etc...) ;
- attitude vis-à-vis de l'utilité des centrales.

Cette analyse confirme les conclusions tirées par Fields d'une vaste enquête, à savoir que les facteurs "attitude" et "sensibilité" sont importants dans la prévison des réactions au bruit, alors que les facteurs démographiques (âge, statut de propriétaire ou locataire, etc...) ne le sont pas.
Cette analyse suggère aussi qu'en moyenne plus de 50% de la variation de réaction peut être expliqué par les facteurs psychologiques pris en compte dans les enquêtes, ce qui est beaucoup plus que pour le facteur bruit.

Si la pertinence d'un certain nombre de variables psychologiques est établie, il se peut que beaucoup de ces variables ne soient pas encore connues. Mais les recherches actuelles rencontrent un certain nombre d'obstacles pour être vraiment fructueuses. Six obstacles sont présentés ici.

1. La gêne comme réaction au bruit

En plus des effets physiques, psychologiques et psychiatriques du bruit (Kryter 1991, Stansfeld 1992), la réaction subjective d'une population au bruit est plus qu'une simple gêne.

Les études socioacoustiques utilisent de façon presque uniforme la gêne comme critère de réaction de la population, ainsi que M. Schultz l'a fait dans sa synthèse. La peur est aussi quelquefois prise en compte comme critère de réaction ou parfois comme variable modifiante (Fields 1992) ; la perte de sommeil est également étudiée. Toutefois, la réaction au bruit peut être bien plus que la gêne, ou du moins s'exprimer différemment.

Les individus peuvent réagir par des sentiments de colère, de déception, de retrait, d'impuissance, de dépression, d'anxiété, de distraction, d'agitation, d'épuisement. Dans un rapport, qui mériterait d'être plus largement diffusé, Hede, Bullen et Rose (1979) ont dressé la liste des mots utilisés par les personnes pour décrire leurs réactions aux différents bruits. L'étude a montré que beaucoup de mots ne correspondent pas à la gêne. Plus encore, le mot "affecté", a généré plus de réactions que le mot "gêné". La corrélation partielle entre l'exposition au bruit et le fait d'être "affecté" est de 0,25 à gêne constante contre la corrélation zéro attendue si la gêne était le seul composant de la réaction. Il semble préférable de ne pas spécifier au moins une émotion dans une question, pour permettre de détecter des émotions négatives non mentionnées.

Par exemple, l'importance de l'effet, ou l'importance de l'insatisfaction ont été utilisées par Bullen et Hede 1982, et Job et Hede 1989.

Il est nécessaire de réviser l'affirmation selon laquelle la gêne peut rendre compte totalement de la réaction subjective.

2. Facteurs méthodologiques

Il existe un certain nombre de paramètres méthodologiques particulièrement pertinents dans notre domaine. Il est inutile de rappeler ici les problèmes liés aux choix par l'individu lui-même de l'exposition au bruit et les difficultés qui en résultent pour déterminer la causalité, établie par les méthodes transversales.

Cependant, deux problèmes méthodologiques de mesure des variables psychologiques, continuent à présenter des conséquences facheuses dans les recherches socioacoustiques. Le premier est l'utilisation d'une question unique pour mesurer la réaction au bruit ; il est prouvé que cela entraine une mesure moins fiable que si l'on utilise plusieurs questions combinées de manière à produire une échelle (voir Job, 1988, 1991) De plus, l'utilisation d'une seule question ne permet pas d'estimer la consistence interne de la réaction. Le deuxième problème méthodologique est que, si l'on a des questions relativement standardisées pour déterminer la sensibilité au bruit (Weinstein 1980), la mesure de l'attitude face à la source de bruit demeure non standardisée et varie beaucoup d'une étude à l'autre. Même dans le cas où plusieurs questions sont utilisées pour définir l'attitude, les questions connues sont rares. Nos propres recherches sont une démonstration malheureuse de ce fait : la comparaison des échelles utilisées par Bullen, Hede, et Kyriacos en 1986, Bullen, Hede et Job en 1991, a montré qu'il y a 2 questions seulement à peu près comparables, sur un total de 10.

Néanmoins, une synthèse des questions utilisées dans un grand nombre d'enquêtes sur l'artillerie, l'aviation, les rifles ranges, les centrales et des attitudes identifiées comme importantes dans l'étude de Fields (1992) suggère qu'une mesure standardisée de l'attitude est possible même pour des sources de bruit assez différentes. Une telle échelle est proposée dans le tableau 1. L'utilisation d'une échelle standardisée permettrait de pouvoir mieux comparer les enquêtes et permettrait d'obtenir une mesure globale des différentes composantes de l'attitude vis-à-vis d'une source de bruit.

Avec des réponses échelonnées de 1 = pas du tout d'accord à 5 = complètement d'accord, 5 niveaux d'attitude peuvent être déterminés grâce à la série de questions proposées. Les échelles et les niveaux sont les suivants :

Attitude 1 (on ne fait pas suffisament de choses)
Attitude 2 (danger)
Attitude 3 (manque de fonction)
Attitude 4 (alternatives)
Attitude 5 (autres effets physiques)

Cette échelle inclut une réévaluation permettant à un résultat, sur n'importe quelle échelle, de représenter le niveau moyen d'accord (de 1 à 5) par rapport à 1 une attitude décrite de façon négative.

3. Certains paramètres de prévision du bruit peuvent être d'efficacité différente dans la prévision de la réaction

Une des conséquences de l'utilisation d'une question unique ou de questions combinées est qu'on ne sait pas si certains paramètres sont plus ou moins pertinents pour la prévision des réactions, selon le type de réaction considérée.
Un premier exemple est que le bruit nocturne est peut-être un meilleur indicateur de la perturbation du sommeil que le bruit diurne, alors que le bruit diurne sera un meilleur indicateur pour la perturbation des activités extérieures. La possibilité qu'il existe un certain nombre de telles relations devrait être examinée. Un certain nombre de possibilités sont prévisibles par des enquêtes pertinentes et par la théorie. Ainsi la sensibilité au bruit peut être un paramètre de prévision plus ou moins bon des perturbations psychiatriques, bien que la cause ne soit pas entièrement claire (Stansfeld, 1992).

Tableau 1 : Un questionnaire classique sur les comportements face à une source de bruit.

Nous nous intéressons à ce que vous pensez au sujet de ....(nom de la source de bruit). Dites nous si vous êtes tout-à-fait d'accord, d'accord, sans opinion, pas d'accord, pas d'accord du tout avec les affirmations suivantes : - les autorités de ....font de leur mieux pour réduire le bruit ; - ....est un danger dans la région ; - ....présente un intérêt pour la région ; - ....est visuellement attractive ; - le gouvernement ne prend pas assez de mesure pour stopper la pollution sonore ; - ....est une perte d'argent ; - ....crée une pollution atmosphérique dans la région ; - les (ouvriers, pilotes, conducteurs, tireurs) sont préoccupés par le bruit qu'ils provoquent ; - ....ne représente pas une menace pour la sécurité ; - ....remplit une fonction importante ; - il y a de meilleurs choix qu'utiliser ....; - on pourrait faire beaucoup plus pour réduire le bruit de .... ; - ....apporte des avantages : (préciser : emploi, défense, production, autre).

L'impression subjective, ou le fait subjectif, de ne pouvoir contrôler ou prévoir le bruit gênant peut être un paramètre plus ou moins efficace pour déterminer les réactions de stress, de dépression. Il peut aussi être en relation avec le système circulatoire dans la mesure où le caractère imprévisible et incontrôlable du bruit augmente les niveaux de cholestérol chez les animaux de laboratoire. (Brennau et al, 1992). Il faut noter que ces paramètres varient : certaines personnes peuvent, au moins partiellement, contrôler leur exposition au bruit en fermant les fenêtres, en utilisant l'air conditionné ou en changeant de pièce. Certains considèrent qu'ils peuvent prévoir ou agir, alors que d'autres pensent que non. Certains bruits sont plus prévisibles : le bruit de circulation est de façon évidente plus élevé à certains moments du jour et certains jours de la semaine ; les bruits lents ont un niveau de crête qui peut apparaître plus prévisible que les bruits impulsifs. Cette dernière observation peut conforter les recherches déjà très documentées sur les réactions plus fortes aux bruits impulsionnels qu'aux bruits non impulsionnels, à niveau sonore égal.

4. Le sens de la causalité n'est pas clair

Une conséquence des méthodes transversales communes à toutes les recherches socioacoustiques est que les corrélations observées sont muettes sur le sens de la causalité.

Un examen minutieux des interrelations peut nous apporter des informations (Mc Kennel, 1978). Deux alternatives évidentes et valables sont possibles : des manipulations expérimentales et des études longitudinales.

La nécessité de faire de telles études avait déjà été affirmée (Berglund, Berglund et Lindvall, 1984) et de telles études ont été faites (Stansfeld 1992).

Il n'en demeure pas moins que ces études devraient dépasser leur forme actuelle. Une extension intéressante serait d'appliquer sur le terrain les méthodes expérimentales de laboratoire. Par exemple, on pourrait obtenir d'avantage d'informations sur le rôle causal des comportements en faisant des manipulations sur le comportement des personnes (avec un groupe témoin) avant de lancer l'enquête. De telles expérimentations sont possibles à travers des épreuves écrites ou verbales.

L'exposition au bruit -et le comportement- sont aussi manipulés par les mesures publiques de lutte contre le bruit. Une isolation plus ou moins efficace, qui peut néanmoins entraîner une réaction uniforme, permettrait une comparaison entre la réduction du bruit et l'amélioration du comportement, qui permettrait de rendre compte des changements de réaction.

Finalement, avoir des personnes ayant des activités spécifiques alors qu'elles sont exposées au bruit est une expérimentation qui peut éclairer le rôle de l'activité, au moment de l'exposition au bruit, dans le niveau de réaction.

5. Des variables psychologiques qui méritent plus d'attention

Alors qu'un grand nombre de variables psychologiques et démographiques ont été examinés dans les études socioacoustiques, quelques variables pertinentes n'ont pas retenu l'attention. En voici un exemple : les agents stressants et les facteurs de risque autres que le bruit peuvent contribuer à la réaction. Le bruit peut être la "petite goutte" dans l'apparition de la gêne ou de l'insatisfaction.

L'incontrolabilité ou l'imprévisibilité du bruit peuvent être des variables importantes avec une pertinence théorique notable (voir plus loin). La négativité comme trait de caractère semble influer sur la réaction dans le sens où on recense plus d'évaluations négatives du bruit chez des personnes hautement négatives. Si ceci demande plus d'attention, on ne sait pas jusqu'à quel point ce facteur est utilisé par mégarde par des réponses négatives sur l'échelle de la sensibilité au bruit ou l'échelle des comportements.

Les activités de la personne interrogée au moment où se produit le bruit peuvent être un critère pertinent. Certaines activités telles que conversation téléphonique ou sommeil sont plus perturbées par le bruit que d'autres telles que tondre sa pelouse par exemple.
Un groupe très intéressant à étudier dans ce domaine est celui des travailleurs postés qui tentent de dormir à des moments plus bruyants. Berglund, Harder et Preis (1991) ont des résultats d'études qui confirment bien ce rôle de l'activité pratiquée au moment de l'exposition au bruit : ils ont montré que le fait de comprendre ou non la conversation est un facteur important dans la gêne, de même que les interruptions de bruit ou les plages de silence. Alors que les enquêtes comportent souvent des questions telles que "le bruit perturbe-t-il certaines activités ?", la façon dont les personnes sont impliquées dans ces activités n'est jamais abordée. Il est peut-être erroné de donner le même score à deux personnes qui disent toutes deux que le bruit perturbe la lecture, si l'une lit plusieurs heures par jour et l'autre une fois seulement au cours de plusieurs mois.
Il est évident que cette variable doit apparaître dans les prochaines enquêtes.

6. L'application de la théorie psychologique

Si la recherche a été fructueuse dans des domaines appliqués et dans la modélisation mathématique des réactions, la réaction humaine est encore mal comprise au plan théorique. Une des raisons de la prédominance des études appliquées est la forte proportion de crédits de recherche à court terme provenant d'organismes gouvernementaux ou même locaux, souvent confrontés à des plaintes de la population . Dans un tel contexte, la théorie est souvent négligée. Toutefois, les études fondamentales devraient être poursuivies et un certain nombre de théories du domaine psychologique pourraient être importées. Trois sont ici suggérées.

Stansfeld (1992) a observé que chez la femme, la dépression est liée à la sensibilité au bruit et que cette sensibilité au bruit, bien que diminuant légèrement, demeure élevée après la guérison. Chez l'homme, des interactions entre sensibilité, exposition au bruit et morbidité psychologique ont été observées. Finalement, la sensibilité au bruit permet de prévoir la réaction physiologique au bruit.

Ce schéma suggère une impossibilité de filtrer ou d'ignorer les stimuli sonores non signifiants chez les personnes avec une prédisposition psycho-pathologique. Cette théorie du désordre psychiatrique existe depuis un certain temps et elle est pertinente quant à la réaction au bruit.

Si ceux qui ont une prédisposition à une maladie psychiatrique sont moins capables d'ignorer les stimuli non pertinents (y compris les stimuli sonores), alors l'exposition au bruit est susceptible d'avoir sur eux un plus grand impact que sur les autres. Cette possibilité mérite des recherches supplémentaires.

Les autres théories sont issues de travaux menées sur des animaux de laboratoire et sur les humains exposés à des bruits incontrolables / imprévisibles. L'utilité de ces études tient au caractère, au moins partiellement, incontrolable et imprévisible du bruit dans l'habitat.
De plus, la variabilité réelle ou perçue du contrôle ou de la prévisibilité nécessite des recherches sur l'impact de ces variables sur les résultats théoriquement prévisibles.
La théorie de l'impuissance suggère que l'incontrolabilité conduit à une altération cognitive, une perte de motivation, des changements émotionnels et même de la dépression (Maier et Seligman, 1976). La théorie de l'anxiété considère que c'est le caractère imprévisible plutôt qu'incontrolable qui est le facteur déterminant dans les effets observés, incluant en particulier une crainte exagérée et de l'anxiété. La théorie de l'anxiété est décrite par Minor et al (1991).

Finalement, le terrain commun de la dépression connue rend l'application de ces théories plus attirante :
L'exposition au bruit et la sensibilité ont été des facteurs de prévision des admissions en hôpital psychiatrique (Kryter 1990) et des dépressions en particulier (Stansfeld 1992 ; Stansfeld et al). L'impuissance devant l'évènement et l'anxiété qui en résulte comme facteurs pouvant expliquer certaines dépressions ont conduit à une impressionnante série de parallèles entre les conséquences d'une exposition d'animaux et d'humains à des bruits incontrolables, imprévisibles et les caractéristiques de la dépression nerveuse.
Ces caractéristiques connues incluent :

- guérison par des antidépresseurs mais pas par d'autres psychotropes ;
- guérison par électrochocs ;
- dégradation cognitive ;
- réduction de l'activité motrice ;
- anxiété et peur accrues ;
- perte d'appétit, perte de poids ;
- consommation plus systématique d'aliments aux goûts amers / singuliers;
- sensibilité au test de suppression de la dexaméthosone ;
- perception du contrôle personnel diminuée.

Pour une synthèse de ces parallèles, voir Dess (1991), Minor et al (1991) et Overmier et Hellhamme (1988).

Un moyen rétrospectif d'examiner le rôle éventuel de l'incontrolabilité/imprévisibilité et de l'impuissance du sujet est d'étudier les réponses à certaines questions dans les enquêtes précédentes. Dans un certain nombre d'enquêtes menées en Australie, 2 questions étaient fréquement posées. Les personnes devaient donner leur niveau d'agrément concernant les affirmations suivantes :

- "le gouvernement ne fait pas suffisamment de choses / ne prend pas en compte la pollution sonore" et "cela ne sert à rien de se plaindre car de toute façon personne ne fera rien".

La seconde question peut être considérée comme une expression de l'impuissance.

Il semblerait que l'accord sur la première question soit plus pertinente pour les sources de bruit de l'Etat (et spécifiquement de la Défense) que pour les sources de bruit civiles. Les résultats sont présentés dans le tableau de gauche de la figure 1. Ces résultats confortent la différence proposée. L'application de ces théories permettrait de prévoir qu'avec moins de controlabilité, il y aura plus d'accords sur l'expression de l'impuissance chez les riverains d'installations bruyantes régies par l'Etat.

Les informations disponibles, dans le tableau de droite de la figure 1, confortent cette prévision.

L'application de ces théories sur l'anxiété et l'impuissance suggère des relations entre des variables spécifiques : niveau réel et perçu du caractère contrôlable et prévisible du bruit, dépression, anxiété, peur (voir Abramson, Seligman, Terasdale, 1978).

Les parallèles identifiés suggèrent que des recherches sur ces possibilités seraient nécessaires et pourraient expliquer certaines variances dans les réactions individuelles au bruit.

Conclusion.

On peut tirer de ce qui précède les conclusion suivantes :

- les variables psychologiques sont primordiales et méritent une plus grande attention ;

- la réaction au bruit est plus que la gêne ;

- la fiabilité de la mesure de la réaction (et les autres variables subjectives) est importante ;

- il reste des variables psychologiques encore inexpliquées.

L'application des théories de la psychologie a une valeur potentielle dans la découverte de variables qui pourraient aider à prévoir les variations de réaction au bruit et à avoir une meilleure compréhension théorique des réactions humaines au bruit.

Figure 1 :
Attitude vis-à-vis des sources de bruit en fonction de leur origine, civile ou étatique.

Le tableau de gauche montre l'accord (sur l'échelle de 5 = tout à fait d'accord à 1 : pas du tout d'accord) sur le fait que le gouvernement n'en fait pas assez en matière de lutte contre le bruit. Les résultats suggèrent des différences entre les sources de bruit civiles et les sources de bruit appartenant à l'Etat.

Le tableau de droite montre l'accord (sur la même échelle) sur le fait que cela ne sert à rien de se plaindre parce que personne ne fait rien. Les résultats montrent qu'il y a un plus grand sentiment d'impuissance lorsqu'il s'agit de sources de bruit appartenant à l'Etat.

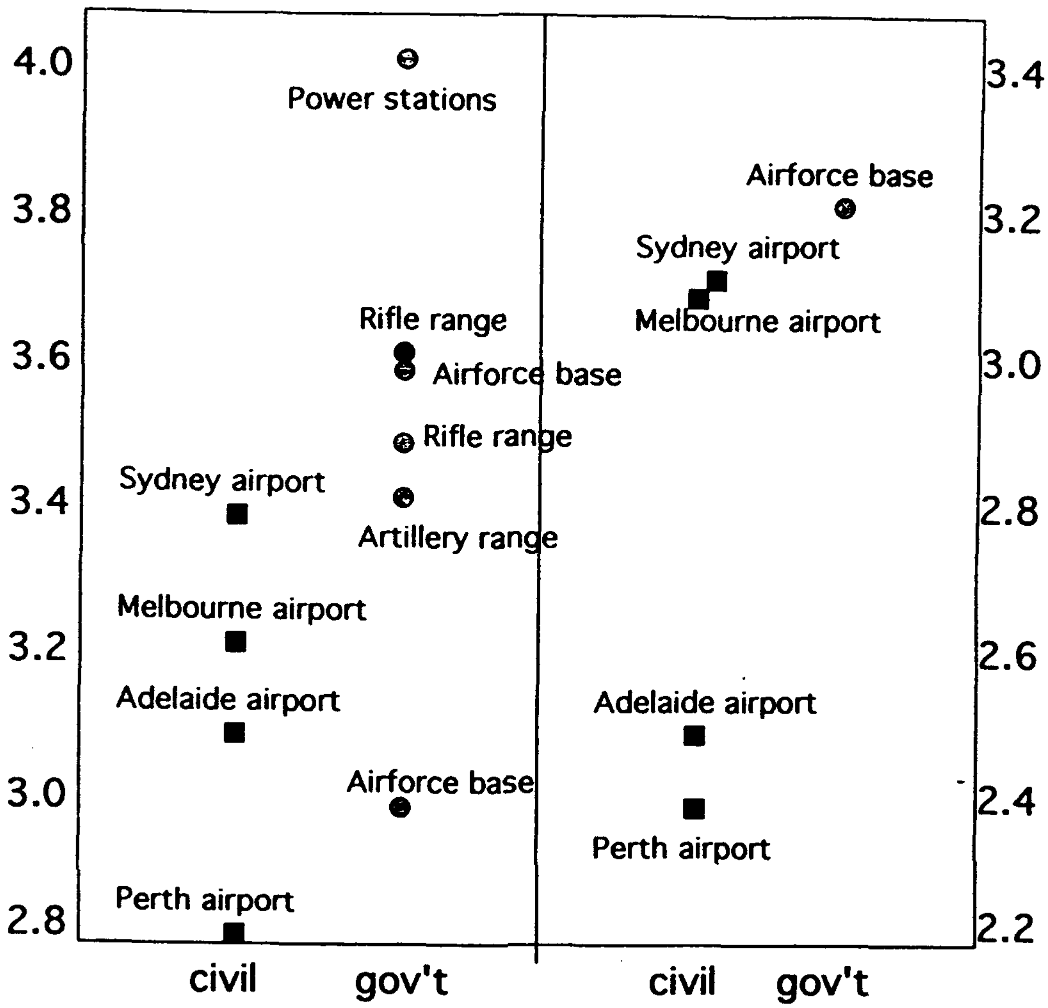

Figure 1: Attitudes to the noise source as a function of civil versus government run noise sources.

The left panel shows agreement (on the scale 5=strongly agree to 1= strongly disagree) for the claim that the government is not doing enough about noise. Results suggest rational differences between civil and government noise sources.

The right panel shows agreement (on the same scale) for the claim that there is no use complaining about the noise because no one will do anything about it anyway. Results suggest more helplessness with gov't noise sources.

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TECHNICAL ASPECTS OF NOISE IMMISSION REDUCTION FROM LAND TRANSPORT

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THE EVOLUTION OF NOISE LEVELS

In the developed countries the disturbance most frequently cited by respondents to surveys is noise in the home. This finding also emerges from an analysis of complaints relating to the environment, the majority of which concerns noise. About 17% of the inhabitants of industrial countries are currently exposed to noise levels exceeding the recommended limit of LeqA of 65 dB (A) on the façade of their houses. The prime offending source of noise in terms of the number of people disturbed is road traffic, followed by neighbourhood and aircraft noise. In less developed countries, the disturbance can increase as it has been noticed in the Mediterranean countries.

In Greece for example, noise levels recorded in secondary towns are mainly due to motorcycles which constitute a general transition - as already observed in Asia - from non motorised trips to cars. 70% of the Athens population are reported to be submitted to LeqA levels exceeding 70 dB(A). At present, it can no longer be said that people better get used to noise in the South than in the North. Indeed, ways of living, climates, vehicle fleets and tourist inrushes make noise-related nuisance at least as high and sometimes more difficult to control in some Southern countries as in Northern countries.

The limits determined for various land uses are *very similar in all countries* (Table 1, ref. 1). If the example of Switzerland is to be followed, where the proposed limits for planning are far lower than for protection as regards new projects (Table 2), a significant increase in demand for noiseless transport systems will be observed. This is already the case in Swiss and Austrian alpine valleys and in some German cities.

Table 1. Road traffic noise limits.
(Leq A).

COUNTRY	FRANCE		AUSTRIA		ITALY	
Noise Index / Land use zone	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Hospitals. Schools etc.	57	52 **	45-50	35-40	50	40
Residential area	60	55	55	45	55	40
Mixed area	65	57	60	50	60-65	50-55
Industrial area	65		65	55	70	60*-70

* industrial areas with low density of residential buildings.
** except schools

Table 2. Swiss standards for noise at night (ref.2)
(Leq A)

Area types	Planning	Protection
I	40	60
II	45	65
III	50	65
IV	55	70

I. THE ROAD VEHICLES

As road traffic is the most important noise source, a great deal of research has been developed since 1962.

I.1 Noise legislation and incentives for quiet vehicles.

Todays vehicle noise legislation - particularly in Europe and Japan - demands the development of low noise vehicles. In European Community the permitted noise levels emissions from road vehicles are enforced by the EEC (see **table** 3). Since 1970, the decrease in the noise limits is significant.

Table 3. Maximum acceptable noise levels for the new vehicles in the EEC
(iso conditions dBA)

Type of vehicle	1970	1982	1989	1995 (proposed)
Private cars	82	80	77	74
Vehicles other than private cars and having a GVW of not more than 3.5 tonnes (vans)	84	81	79	76-77
Public passenger transport vehicles having a GVW of more than 3.5 tonnes and an output power under 150 kw (buses)	89	82	80	78
Commercial vehicles having a GVW of more than 12 tonnes and fitted with engines having an output power equal to or more than 150 kW	91	88	84	80

GVW : Gross vehicle weight.

Environmental traffic management schemes which restrict vehicle movements are in widespread use in OECD countries. In the 1980's different schemes restricting the movements of noisy vehicles and financial incentives for low noise trucks have been introduced in Germany, Austria, Netherlands and the United Kingdom. Severe restrictions or prohibitions in terms of place or time and place may be placed on the movements of heavy goods vehicles whilst "low-noise" vehicles may be exempted from the controls. This approach can favor the market of silent vehicles. For German low noise truck label (1984), the ISO noise limit is 77-80 dB(A). The costs of these trucks are 3 - 9% higher.

I.2 The sources of vehicles noise.

Any attempt to control noise must start from an understanding of the sources of that noise. Since the development and testing of the early quiet vehicle prototypes, substantial gains have been made in both the understanding of the nature of the problem of vehicle noise quietening and in the development of sophisticated signal processing techniques for both source identification and analysis. The result is that most vehicles from the smallest motorcycle to the most powerful truck can be quietened to the extent that it is now possible to think in terms of all production vehicles achieving the much publicised target of 80 dB (A) or below under the standard test.

The contributions from the different basic sources to the total amount of noise depend on the vehicle type, speed and acceleration (see table 4).

Table 4. Approximate contributions from the different sources to the total amount of acoustic power of a well maintained road vehicle (ref. 3)

Road conditions / *Source of noise.*	**Urban streets**		**Open road**	
	Light vehicles	Heavy vehicles	Light vehicles	Heavy vehicles
Air intake inlet,	*			
Exhaust pipe assembly and outlet	*		*	**
Engine block	*	***		**
Gear box and transmission	depends			
Cooling fan		**		
Tyre-road surface contact	* to **		***	*

* high contribution, ** very high contribution, *** major contribution

The engines

The engine noise level does increase with engine running speed, it does not increase so rapidly with the engine capacity C and we can say that in principle the total noise level in dB(A) varies as follows (ref. 4):

Diesel engines: $L_A = 30 \log N + 17.5 \log C$

Spark ignition engines: $L_A = 50 \log N + 17.5 \log C$

These equations show that for the same power output, a large capacity engine, which will be running at a lower speed, should be quieter than a faster running engine.

The tyre-road surface contact

The results of some early work suggested that there was some relation between the skid resistance of a road surface and the generation of noise. However, as a result of work carried out since 1979 it is now known that this relation is only true on being considered for each particular type of road surface. Thus there is no basic relation between the average depth of the road surface texture and the generation of noise.

Rolling noise increases very rapidly with vehicle speed V because the overall acoustic power that is generated increases in proportion to the third to fourth power of V. Thus we have for the peak noise level :

$$L_A = 30 \text{ to } 40 \log V + \text{constant}$$

With different tyres, the noise level for the same road surface can differ by nearly 8 dB in the case of cars and by more than 12 dB in the case of heavy lorries.

The rolling noise is due to a number of different effects as is shown in Table 5 . So far as the production of noise is concerned we can classify the surface texture of the road surface in terms of the power spectral density of the longitudinal profile for wavelengths ranging from 2 to 200 mm (ref. 5) . If we define the mean square of the surface irregularities over a range of wavelengths λ as T_λ, then the 'texture factor' can be expressed as: $L_\lambda = 10 \log_{10} T_\lambda/10^{-12}$ where L_λ is expressed in dB with reference to a level of 10^{-12} m^2. On making use of laser beams it is now possible to determine the power spectral densities of road surface profiles with a high degree of accuracy and at low cost. Surfaces having a high 'texture level' give rise in particular to radial excitation of the tyre and type I phenomenon predominate. Surfaces having a low 'texture level' give rise in particular to type II and type III disturbances.

Table 5. Noise due to tyre-road contact.

	Phenomenon	Road surface characteristics
I	Vertical excitation and radiation of noise from the tyre casing	Longitudinal profile (macrotexture) Mechanical impedance at the point of contact (elastic properties of the road)
II	Suction and expulsion of air (air pumping and air pocket resonance)	Geometry and porosity
III	Tangential excitation as a result of stick and slip action	Physico-chemical properties and longitudinal profile

The importance of the impedance of the road surface is not very well understood : road surfaces having a high mechanical impedance (hydraulic concrete or an old bituminous surface) tend to give rise to a greater degree of noise than road surfaces such as recently layed bituminous surfaces, although the difference in noise level amounts in fact to only a few decibels.

I.3. Automobiles

Automobiles are, in practice, the quietest vehicles in the urban traffic stream except for some Diesel cars. Noise level reductions have been achieved by up-grading of the engine and attention to the exhaust. In Germany, treated diesel taxi ISO noise has been reduced from 80 dB(A) to 74 dB(A). Encapsulation of the engine and transmission has generally not been necessary to achieve a drive-by noise limit of 77 dB (A) ; indeed, it is likely that a somewhat more stringent target of perhaps 75 dB (A) could be achieved with little or no penalty.

On highspeed ways, automobiles may be noisier than heavy vehicles, owing of the tyre-road noise.

I.4 Heavy Goods Vehicles

The noise level of trucks is frequently some 10 dB(A) higher than that of cars in consequence of the diesel engines used and the greater engine power ; but there seems good likelihood that regulations of noise

emissions will reduce this gap (see Table 3). Furthermore just in time delivery practices are hostile to the environment, the need for night operations and the legislation may help for the introduction of very quiet heavy lorries.

Trucks engines and exhausts emit **low frequency** noise at a much higher intensity than do cars. The propagation of this noise through the air may produce the vibrations of the windows and sometimes even of the walls and the floors of the nearest buildings.

For vehicles which do not meet the required noise levels, the manufacturers apply in most cases any type of shielding to meet the demands with todays engine designs. To achieve even lower noise levels, as already in force in some European countries, these vehicles are today equipped with almost full powertrain enclosure. Shielding and enclosures are regarded as additional parts with disadvantages: they bring with them the attendant problems of engine cooling and increase weight, maintenance problems and costs.

The size of the silencers associated with the air intake and engine exhaust systems is a problem in that their effectiveness at low frequencies is a function of their volume.

Experience with the various quiet goods vehicle programmes suggests that with a production quiet engine, acoustic side-screens and a large volume exhaust silencer, a maximum weight goods vehicle can achieve a drive-by noise level of 82-83 dB(A) (ref 6). With a tunnel enclosure the same vehicle could achieve 80-81 dB(A). Complete encapsulation of the engine allows vehicles to achieve noise levels as low as 77 dB(A) under the standard tests.

I.5 Public transportation. Buses

The annoyance which buses produce can be high for example at night time and/or near the bus stations.

Generally the engines of buses are truck engines. Silencers and acoustic shieldings can be developed in a short time. Fully encapsulated engines with remote cooling are used on buses (and on special low noise delivery vehicles) in Germany. The critical factors may well be the availability of suitable engineering and maintenance conditions. In Germany 90% of new registered buses have encapsulated engines (noise levels in the range 77 - 82 dB(A))

Very encouraging experiments have been done with electric buses ; trolley buses are in use in many towns. Several mechanical and electrical innovations have been developed for years particularly in Germany or Sweden but electrically powered buses with battery or trolley lines are expensive as are also the various hybrid buses with energy recovery systems.

II. THE TRAINS.

European and Japanese populations are highly submitted to train noise particularly in urban areas and valleys (see table 6).

Table 6. Examples of exposure to train noise in Europe (ref. 7)

Country	Percentage of the population exposed to a noise level exceeding			
	55 dB(A)	60 dB(A)	65 dB(A)	70 dB(A)
Germany	13,0	5,0	1,0	
France	1,4	0,8	0,4	0,15
Switzerland	20,0	11,0	4,0	1,0

II.1. The sources of train noise.

Noise from tracked vehicles comes from a variety of sources, including the propulsion system, the wheel/rail interaction and aerodynamic noise. The propulsion system tends to dominate noise at low speeds, with electric traction considerably quieter than diesel or turbine powered trains. Wheel/rail interaction becomes the dominant noise source for speeds above 50 mph for conventional electric trains. For speed higher than 300 km/h aerodynamic noise must be considered. For the time being, rolling noise is increasingly becoming the dominant form of noise.

Rolling noise

The external noise due to the contact between the train wheel and steel rail is a result of complex phenomena. Experimental investigations carried out where rolling noise was presumed to be dominant have shown that the noise levels can be expressed by the following type of equation (ref. 8):

$$L_{max} = 30 \log V + \text{a constant}$$

The differences are partly due to the way in which the noise was measured (more or less long integrating periods). According to this analysis which involves forced vibrations, the speed of displacement of the vehicle is involved in three ways with the emitted noise :

a) Roughness spectrum. Knowing the wavelengths λ of the rail or wheel irregularities the frequency of the emitted noise is given by $f = V/\lambda$ where V is the speed of displacement of the vehicle.
b) Hertz ellipse filtering. This filter acts with respect to the number of wavelengths k of the track or wheel.
c) Level coefficient μ (V). This last term express the variation in the energy injected per unit time as a function of the vehicle speed. As a very first approximation this energy varies as V^2.

Wear of the rails is however a major concern with regard to both running costs and low noise of very high speed trains (except where magnetic levitation is being employed).

For perfect conditions of rail and wheel, this analysis seems inadequate, at high speed the noise could be emitted mainly at resonant vibration frequencies of the wheel and of the rails (ref. 9). In conclusion we must underline that for 10 years our understanding of the generation of wheel-rail noise has been in good progress (ref. 10).

Aerodynamic noise

With the advent of Very High Speed Train, aerodynamic noise sources come into the picture very strongly as speed increases over 250 km/h. Our knowledge of aeroacoustics and the results of measurements confirm the assumption of a rate of increase in the level of aerodynamic noise power with speed of 60 to 70 log V. These relationships are shown in **figure** 1 for typical trains. Both curves apply to conventional trains where wheel/rail sources dominate up to speeds of 150 - 200 mph, after which the aerodynamic noise becomes significant.

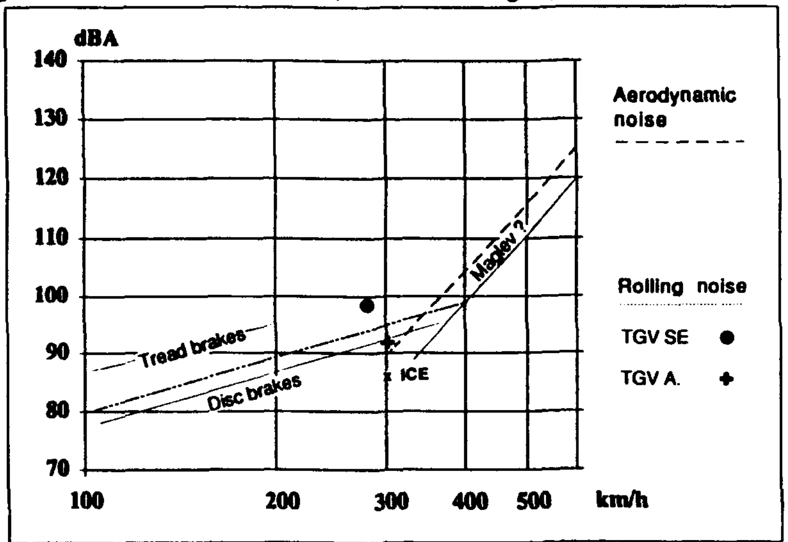
Aerodynamic noise is related to the coefficient of drag of the train. The noise comes from a combination of effects of turbulent boundary layer noise and flow separation noise (ref. 11). Some of the sources of aerodynamic noise are vortex shedding from the wheelset that protrude into the airstream, from the pantograph and from elements on the surface such as windshield wipers. Pantographs together with the cavities under coaches are the main sources of aerodynamic noise. Full scale tests in anechoic wind tunnels are carried out on these items, as well as antennas for passing by noise measurements in full scale tests.

Magnetically levitated vehicles are subject to the same aerodynamic conditions as other trains, but Maglev which have no pantographs could be less noisy at high speed and also at low speed in urban areas (fig. 1). The oscillating magnetic forces create a noise level comparable to those from conventional high speed trains. For the time being, there is no evidence that at high speed maglev vehicles will be quieter than HST.

High Speed Train noise emissions.

In figure 1 noise figures are shown for some of the fastest rail-wheel trains as well as for a maglev system on an aerial structure. The data are plotted as measured or predicted at an international standard distance of 25 meters, corresponding to 75 feet.

Figure 1. Noise levels from HST (wheels and Maglev) at 25 m. from the track.



The noise vs speed curve illustrates the combination of wheel/rail noise and aerodynamic noise (ref. 12). At speeds, below 350 Kph for the TGV, the slope of the curve follows the 30 log speed relationship discussed above. As speed reaches 350 Kph, the slope gradually changes to correspond to a sum of wheel/rail noise and aerodynamic noise and at speeds greater than 180 mph, the slope approaches the 60 logs speed relationship of aerodynamic noise.

II.2. Train noise control

Reduction of noise in the community could result from vehicle or track design. Changes to operating patterns such as reducing the speed should have an uneconomical general effect and only a minor acoustical benefit. For example, a 25 per cent reduction of speed from 300 to 225 km/h could only bring a reduction of 4 dB in the maximum noise level and 2.5 dB in Leq_A.

Vehicle - Three categories of measures can be considered (ref. 13):

I. Wheel/rail and structure noise countermeasures : lighter bogies; sleeper and rail fastening equipment with other spring coefficients; resilient wheels; noise-proof cover for bogies; lighter parts for rolling stock; grinding equipment for wheel tread and rail; sliding detectors, etc.
II. Power collection noise countermeasures; pantograph roof cover; use of fewer pantographs; improved pantograph design; trolley wire lubrication; solid lubricating materials.
III. Car body aerodynamic noise countermeasures : smoother end parts of cars, train end shape improvement, etc.

Fitting of skirts over the wheels, are not encouraging because of the inability to shield both wheel and rail. The use of resilient wheels has proved practical only for low speed train because of unacceptable wear rates. Use of articulated vehicles, and hence half of the conventional number of wheels, has proved beneficial, with the TGVs.

Replacing of disc brakes in place of tread brakes allow a significant rolling noise reduction (see table 7) but is difficult on the power cars because of restricted space. This change could bring a significant reduction in power car noise, although it remains to be seen whether a powered disc-braked wheel will remain as smooth as an unpowered on.

Table 7. TGV noise,

TGV	Lmax-25m dBA	Commercial speed (km/h)	Equipment
Paris Lyon	99,0	270	Tread brakes.
Atlantique & Paris Lille	91,5 - 94	300	Disc brakes for passengers cars
Future	minus 3-4 ?		In addition disc brakes on power cars resilient wheels, cover under the coaches

Track - Noise levels reduce as the distance from the track increases, typically falling by 4 to 6 dB each time the distance is doubled but the most effective means of control at present is the installation of barriers or screens alongside the track. A 2 m high absorbent barrier close to the track will reduce noise levels by up to 10 dB. Cuttings have much the same effect as an artificial barrier, and may be more visually acceptable. Running alongside existing railways or motorways, as with the design of the TGV-Atlantique and TGV Paris-North Europe lines, will restrict the noise disturbance to an existing 'noise corridor'.

The new TGV Atlantique line opened in 1989, this TGV carries passengers between Paris and West France at a commercial speed of 300 km/h. A complete noise prediction along the track led to the construction of 11 000 m of earth berm, 17 800 of noise barriers. Some houses have been insulated. The noise barriers are generally made of current concrete.

Comprehensive environmental protection can add significantly to the cost of a new high speed line, anything from 25 per cent on the German Neubraustrecken to perhaps 40 per cent on the earlier proposed British Railway's Channel Tunnel link.

The technology and expertise is now available to produce an environmentally-acceptable high speed rail line, but for speed higher than 350 km/h, the main noise source being the aerodynamic noise, very high acoustic barriers should be needed, that could prove impossible for environmental, confort and cost reasons, can we consider transparent barriers? Some Japanese decision makers seem to believe that they have to limit the HST speed to 320 km/h because the overhelmingly difficulty of the aerodynamic noise reduction.

II.3. Urban guided transport.

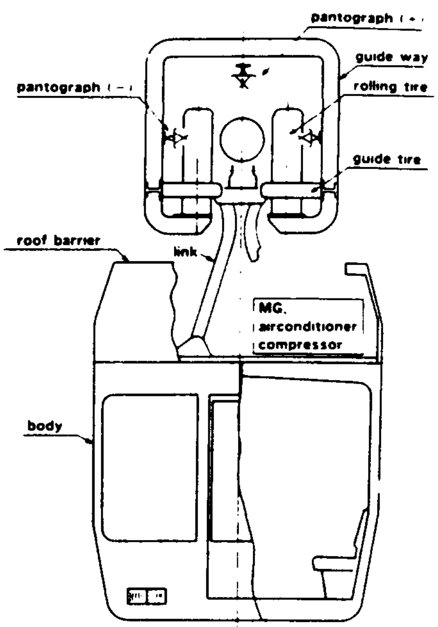
Noise control of elevated railway can be insured by low noise barriers. Generally very low noise levels are obtained with these various systems which are electrically propelled. Furthermore, many elevated low speed railways are fitted with tyres.

For suspended monorails the noise reduction must be reached at the source, in Chiba, at the outskirt of Tokyo, for example, the noise level at a distance of 10 m. from the monorail track is less than 70 dB(A) (ref. 14), figure 2 illustrates the arrangement of the sources. Several techniques for the reduction of the noise outputs from each component have been used :

Measures for noise reduction (ref. 14)

Component	Measures
Bogie	Reduce speed of driving motor. Improve accuracy of gear. Stiffen gear box. Apply damping material to frame.
Tire	Change tread pattern from ribbed to blank.
Pantograph	Low noise type shoe.
Compressor	Barrier above vehicle roof.
Guideway	Apply sound absorbing and damping material.

Figure 2. Noise sources of a monorail vehicle (ref. 14)



Traffic noi · ·pends on the site, on the road or track pavement and on the vehicles noise emissions ; for steady flow ·g traffic the Leq_A is broadly defined by following type of formula:

LeqA=	Parameters
Cte +	Vehicle type
Cte +	Road&tyre surfaces
10 log(Qvl+EQpl) +20 log V	Traffic
-12 log d+10 log θ	Site

The formula illustrates the part of the site and the part of the traffic.

Qvl, Qpl : number of light (<3,5t), heavy vehicles(>3,5t) per hour.
E : acoustic equivalent factor between light and heavy vehicles.
V : traffic speed
d · distance to the road.
θ : angle subtended by the road section from the receiver point.

III.1 Low noise road surfaces

By using a porous surface it is usually possible to obtain a Leq_A reduction of approximately 3 to 6 dB (A) for road traffic at speeds higher than 70 km/h. The reduction of the maximum noise level Lmax could reach 7 dBA. For low-speed roads&streets surfaces ge' clogged with time and noise reduction is reduced down to 0 or 1 dB (A) in just a few year ; the more advanced types of porous surfaces are required, like multi-layer or very thick layer of open asphalt or the air voids content must be particularly high.

With binders made of rubber and bitumen, no sand is necessary for the open asphalt and consequently the asphalt is less costly and the percentage of air voids volume can reach 30% (generally the percentage is 20%). It could give 5-10 dB (A) of noise reduction, but so far several non-acoustical problems remain to be solved.

In most cases, the reduced durability of porous asphalt can lead to costs up to 1,5 or 5 times the cost of conventional road surfaces and there is today (ref 15) a challenge for open asphalt use for urban ways where the road surfaces is frequently destroyed for public works, but, in some cases the noise reducing properties of porous asphalt allow to abstain from noise barriers and therefore get a positive cost benefit ratio.

III.2 Screens

In the noise shade area behind a barrier, the noise reduction is generally higher than 10 dB (A) if the barrier is long enough and if there is no destructive sound reflection. So for low and medium density areas, the noise barriers are widely used in Europe. These barriers can be : banks, wood, glass or metal panels, walls. Most European barriers are deflective and rather cheap ; either the sound reflection by the vertical barrier is harmless or the shape of the barrier avoid harmful reflections ; the common solution is found on inclining the existing noise screen to the vertical—an angle of inclination of 5 to 10° is usually sufficient. The visual intrusion is the main problem. For elevated highways, small parapets may reduce the noise levels by 12-15 dB (A) for the lower buildings.

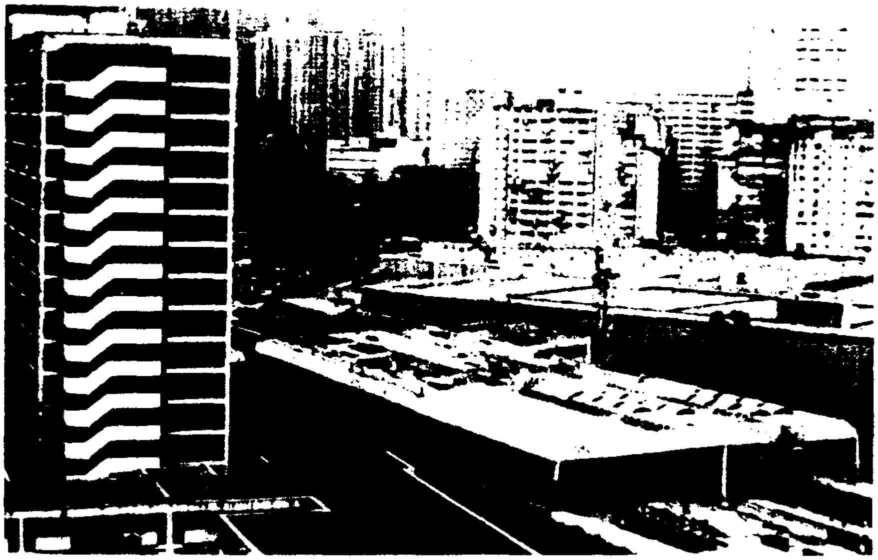
Apart from their acoustic qualities (in particular a minimum mass per unit surface area), the noise screens must be able to withstand the effects of wind, be of durable construction, be made from non-inflammable materials and have an acceptable appearance. Safety requirements also lead to the nee· to locate the screens at a certain minimum distance from crash barriers, this distance depending on the degree to which such barriers are likely to be deformed in the event of an impact (a clearance distance of 1.5 metres is generally required). An exception to this clearance requirement arises in the case of structures that serve as both noise screens and crash barrier.

Absorbent screens are costly and seldom employed in Europe or US. In Japan, absorbent barriers along the highways are used, their visual intrusion is lessened by their uniformity in the country. The material employed in the noise absorbing screens needs to have a Sabine coefficient of absorption of about 0.6 over a frequency range of 250 to 2,000 Herz. The sound absorption capacities must not be affected by the weather conditions or by solar radiation and there should be no risk of the absorbent material making up the screen becoming blocked *clogged* with dust. The absorbent part of the screen can consist of a porous fibre, such as glass wool, etc., protected with perforated steel or plastic sheet covered with another sheet of plastic material to keep out dust. The cost can amount to as much as twice the cost involved in providing reflecting type screens.
Absorbent materials are more commonly provided in the case of locations where there is some protection from the weather such as tunnels, covered roads and underground railways systems.

III.3 Partial covering and complete enclosure

In very densely populated areas with tall buildings, tunnels, complete cover or part covering can lessen the noise by 30 to 10 dB (A), but these means are very costly. In urban areas especially, underground roads and railways are often the only environmentally acceptable solution. The complete enclosure of the road by a solid screen is perhaps the ultimate solution to highway noise pollution. In down town the complete cover allows organisation of urban activities on multiple levels.

Figure 3. Covering in Hong Kong (ref. 16)



There are several examples in Honk Hong (ref. 16) and Germany Complete covering is costly for ventilation and illumination, partial covering is not. Research has concentrated on designing vented covers usually in the form of a grid of plates or sets of louvres; noise reduction can reach 15 dB(A), but the need for noise absorbing lining on the louvres or grid plates has been demonstrated (ref. 17).

IV. BUILDINGS, AND TOWN ORGANISATION

IV.1 Building insulation

The building industry produces efficient panels and windows for noise and thermal insulation. The energy crisis contributes in some way to the acoustical improvements of the buildings but one must be careful to distinguish between the acoustic and thermal properties of the building parts.

The renovation of high rise old building areas bordering suburban highway is practised in France; for example in the city of BRON 2000 dwellings were improved in 1981-85 by the road way authority on the acoustic, thermal and visual point of view. The operation was successful but the neighbour's noise has become more perceptible and induced some complaints !

In Denmark, today about 10% of all housing has been built with consideration to noise requirements.

IV.2 Integrated highway and building design

Development and built areas remodelling along fast roads that run through urban areas depends very much on the need for noise protection. The two extreme possibilities for land use along roads are Distancing building from the road or Complete integration of road and building.

Distancing is not very effective as long as the road remains in direct line of sight of the zone to be considered, as the distance has to be doubled to obtain an attenuation of 3 dB (A).

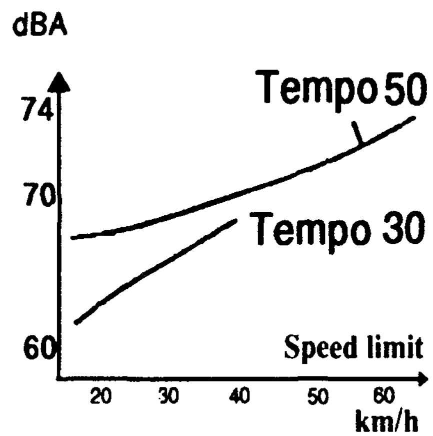
In areas to be built with a high occupation density, the construction of buildings very close or over the infrastructure makes it possible to protect the residential zones and give a major road an urban significance. The waste of land, the background noise, the fragmentation of the town space would be also reduced.

IV.3 City centres. Residential areas - Speed limitations

Prohibition of private traffic in urban areas is appearing in many European towns. The local authorities may very much improve the environment in residential areas by detailed actions on access ways. Traffic signals, parking facilities, road pointing, partial closing of some streets etc. can reduce the speeds and exclude unnecessary through traffic. Interesting concepts have been applied in North Europe, Italy etc (ref. 18).

The acoustical effectiveness of these traffic restraints depends on the percentage of remaining vehicles. In Rome for example, the noise reductions have been as low as 3 to 5 dB(A) because of the relative increase in the traffic speed and in the bus flow (ref. 19).

Figure 5. Speed limit effect on car noise



The modification of speed limits can also influence driving style. For example, in West Germany in the 1970ies, it was found that after the speed limit on several city roads was changed from 50 km/h to 30 km/h the noise levels were reduced partly, as expected, from the reduced speeds of the traffic but also because of changes to the driving style adopted (fig. 5, ref. 20); drivers would accelerate and decelerate less aggressively than when driving in a street with a higher speed limit. The Leq_A noise reduction attributable to driver behaviour changes ranged between 2-4 dB (A) depending upon the speed actually achieved [Tempo 30 in FRG]

It is necessary also to consider peak levels of noise and not simply Leq, particularly at night. The results of the different studies refer to a reduction of 5 dB (A) to 6 dB (A) in peak noise levels (corresponding to what could be achieved by enclosing the vehicle engines).

V. TWO TECHNIQUES FOR THE FUTURE

V.1. Active noise control

The principle of the active control of noise is the destructive interference of an unwanted noise field with a control field generated by additional active sources. The advantage of active noise control results from its potentialities of reducing the weights, sizes, and costs of the noise protection systems required by conventional passive noise protecting techniques, which are - as silencers and noise barriers - generally not very efficient at low frequencies (1600 references on ANC can be founded today in the bibliography). Conversely, active controls are most often particularly operational at low frequencies. Current transport applications mainly relate to aircraft industry and road vehicle inner comfort. In the environmental field, the following points should be considered in the far future:

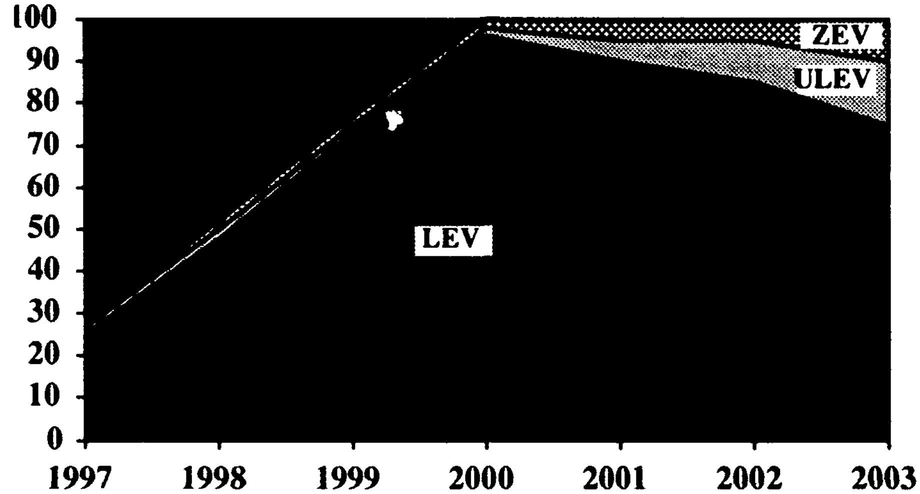
1 - vehicle silencing, in particular electronic muffler systems in which a canceling actuator is connected to the end of an engine exhaust and improve both acoustic emission and fuel efficiency.
2 - cases where active sources can be installed near the emitting noise source (large noise sources are difficult to cope with).
3 - closed areas such as squares or piazzettas where active noise control implementation is more easy than in open areas.
4 - acoustic features of building windows but the experiments appear today as too costly and disappointing.

V.2. Electrical vehicles.

The hydrogen engine is as much noisy as the conventional Internal Combustion engine and hydrogen storage is not very easy. The slow development of electrical batteries has often been disheartening but in the 21th century, electric vehicles will probably be of common use in some urban areas. Batteries already allow a great number of urban travels at a 30-50 km/h speed, advocated by the supporters of "traffic calming". Silent driving at low speeds can be provided only using electrical power.

The South Coast Air Basin authorities in the Los Angeles region decided the progressive introduction of Zero Emission Vehicles, which actually means electric vehicles (fig 6). An invitation to tender for 10,000 vehicles has been made.

Figure 6. Los Angeles 1997 to 2003 programme.Proportions of - Conventional vehicles (US 1992 type) - Low emission Vehicles (LEV)- Ultralow emission Vehicles (ULEV) - Zero Emission Vehicles (ZEV).



Two cases of electrical vehicles should be distinguished:

1) The case of Conventional Electrified Vehicles developed on the basis of Conventional IC Vehicles or very small-sized vehicles (French "voiturettes"). In a number of countries, batteries and electrical motors are just implemented on Conventional IC Vehicle subframes.

2) The case of vehicles initially designed to be electrically powered. For example cars specifically developed to use electrical motors in the wheels.are provided with an excellent 0.19 : Cw drag coefficient that can be accounted for by the car lowered height owing to the absence of exhaust line and driving shaft.

Manufacturers of conventional vehicles all over the world present prototypes of electrical vehicles. "Hybrid" vehicles equipped with IC/battery engines allowing both an ecological urban operation and usual road trips seem to be expensive from a manufacturing and maintenance point of view. In France, the "voiturette" speciality led to various presentations of very small electrically-propelled ecovehicles.

When speed exceeds 40-50 km/h, the electrical vehicle is as much noisy as an IC vehicle since noise emission is thus due to tyres. Thus the development of electrical vehicles could further research studies for the development of noiseless tyres.

In cities, road covering, tunnels and subway alternatives imply construction costs and operation costs for polluted gas extraction devices and, it is clear that in the far future electrical vehicles will be of great interest in this respect.

CONCLUSIONS.

The greatest noise pollution in towns is caused by the current road network. Various methods for the reduction of this noise have been developed and vehicles designers, traffic engineers, road engineers, urban planners and architects must work together for the noise abatement.

Nevertheless if we except some rare new towns it is a very difficult task to get a satisfactory quietness in all urban areas. The road vehicle emissions will be reduced by 5 dB (A) in 10 years, some electric vehicles will be used for specific purposes, but the increasing evolution of mobility and the development prospects for new infrastructures are likely to lead to a significant increase in transport induced noise nuisances despite the vehicle noise emission regulations implemented since the 70's.

For the medium and long range, means aimed at reducing mobility and furthering the shift of motorists to collective or non motorised transport systems can be questioned; but it is clear that furthering motor vehicle traffic will finally involve significant risks of deteriorating the environment quality. Stringent measures intended to limit the use of noisy vehicles in the city, to reorganise heavy and light vehicle traffic, in night and day conditions will be required.

In the long term, active control of noise both for the vehicles and for the outer areas should be considered. Current batteries of electrically propelled vehicles already allow a number of urban trips at a speed of 30 km/h. This could provide the conditions for "calmed traffic" in urban residential areas and the peaceful coexistence of different non motorized street users.

The organisation of both public and private project management for development zones along transport infrastructures can make it possible to find more economical and more environment friendly solutions than rcurrent palliative means (distance, screens, etc.). The active use of town plannings is the most rational way of preventing the occurrence of new noise pollution. The municipalities have to pursue more active planning, in which consideration is given to all environmental conditions, such as noise, air pollution, accidents, visual intrusion etc.

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ASPECTS TECHNIQUES DE LA RÉDUCTION DES ÉMISSIONS DE BRUIT DUS AUX TRANSPORTS TERRESTRES

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L'ÉVOLUTION DES NIVEAUX DE BRUIT

Dans les pays développés, la perturbation la plus souvent citée par les personnes interrogées lors des enquêtes est le bruit dans leur domicile. Cette situation est confirmée également par une analyse des plaintes liées à l'environnement, dont la majorité concerne le bruit. Près de 17% des habitants des pays industriels sont actuellement exposés à des niveaux de bruit dépassant la limite LeqA recommandée soit 65 dB(A) en façade de leur maison. La source responsable principale du bruit est le trafic routier, suivi par le bruit de voisinage et le bruit d'origine aéronautique. Dans les pays moins développés, la perturbation due au bruit augmente comme il a été noté dans les pays méditerranéens.

En Grèce, par exemple, les niveaux de bruit enregistrés dans les villes secondaires sont principalement dus aux cyclomoteurs qui constituent la transition générale - comme déjà observé en Asie - du trajet non motorisé vers la voiture. 70% des Athéniens seraient soumis à des niveaux de LeqA excédant 70 dB(A). A présent, nous ne pouvons plus dire que les populations du Sud supportent mieux le bruit que celles du Nord.

Les limites déterminées pour les différents usages terrestres sont très similaires dans tous les pays (Tableau 1). Si l'exemple à suivre est celui de la Suisse, où des limites proposées pour la planification sont bien plus basses que pour la protection en ce qui concerne les nouveaux projets (Tableau 2), une augmentation significative de la demande pour des systèmes de transports silencieux sera observée. C'est déjà le cas dans les vallées alpines Suisses et Autrichiennes et dans certaines villes Allemandes.

Tableau 1. Limites du bruit du trafic routier (Leq A). réf. 1

PAYS	FRANCE		AUTRICHE		ITALIE	
Index de bruit / Types de zones	**Jour**	**Nuit**	**Jour**	**Nuit**	**Jour**	**Nuit**
Hôpitaux, Écoles etc.	57	52 **	45-50	35-40	50	40
Zones résidentielles	60	55	55	45	55	40
Zones mixtes	65	57	60	50	60-65	50-55
Zones industrielles	65		65	55	70	60*-70

* zones industrielles ayant une faible densité d'immeubles résidentiels.
** sauf les écoles.

Tableau 2. Standards Suisses pour le bruit de nuit (réf. 2) (Leq A)

Aires types	Planification	Protections
I	40	60
II	45	65
III	50	65
IV	55	70

I. LES VÉHICULES ROUTIERS

Le trafic étant la source la plus importante de bruit, de nombreuses recherches ont été développées depuis 1962.

1.1 Législations sur le bruit et incitations pour des véhicules silencieux.

La législation sur le bruit des véhicules - particulièrement en Europe et au Japon - demande le développement de véhicules à faible bruit. Dans la Communauté Européenne, les niveaux d'émission de bruit de véhicules autorisés sont déterminés par la CE (voir Tableau 3). Depuis 1970, la baisse des limites de bruit est significative.

Tableau 3. Niveaux de bruit maximum acceptés pour les nouveaux véhicules dans la CEE (conditions ISO dBA)

Type de véhicule	1970	1982	1989	1995 (proposés)
Voitures privées	82	80	77	74
Véhicules autres que les voitures privées et ayant un PM inférieur à 3.5 tonnes (vans)	84	81	79	76-77
Véhicules de transport public ayant un PM supérieur à 3.5 tonnes et un rendement électrique inférieur à 150 kW (autobus)	89	82	80	78
Véhicules commerciaux ayant un PM supérieur à 12 tonnes et pourvus de moteurs ayant une puissance électrique supérieure ou égale à 150 kW	91	88	84	80

PM : Poids Maximum.

Les schémas de gestion de trafic qui restreignent les mouvements des véhicules sont en nombre croissant dans les pays de l'OCDE. Dans les années 80, différents schémas restreignant la mobilité des véhicules bruyants, et des incitations financières pour les camions à faible bruit ont été introduits en Allemagne, Autriche, Pays-Bas et Royaume-Uni. Des restrictions sévères ou des interdictions en terme de stationnement ou de durée de stationnement ont été imposées aux trajets des poids lourds, alors que les véhicules "à faible bruit" peuvent être exemptés de ces restrictions. Cette approche peut favoriser le marché des véhicules silencieux. Pour le label allemand des camions à faible bruit (1984), la limite de bruit ISO est 77 - 80 dB(A). Le coût de ces camions est 3 à 9% plus important que le coût des camions conventionnels.

1.2 Les sources du bruit dû aux véhicules

Toute tentative de contrôle du bruit doit débuter avec de la compréhension des sources du bruit. Depuis le développement et les tests des premiers prototypes de véhicules silencieux, des progrès substantiels ont été obtenus autant pour comprendre la nature du problème lié à l'atténuation du bruit des véhicules que pour le développement de techniques de travail sur des signaux sophistiqués destinés à l'identification des sources et à leur analyse. Il en résulte que la plupart des véhicules, du plus petit cyclomoteur au camion le plus puissant, peuvent être rendus silencieux dans la mesure où il est possible à présent de penser en fonction d'une production globale de véhicules satisfaisant la cible très médiatisée de 80 dB(A) des tests standards.

Les contributions des différentes sources élémentaires à l'émission totale de bruit dépendent du type du véhicule, de sa vitesse et de son accélération (voir tableau 4).

Tableau 4. Contributions approximatives des différentes sources à la somme totale de la puissance acoustique (réf. 3) (cas d'une route bien entretenue)

Conditions de la route / ***Source du bruit.***	**Routes urbaines**		**Routes interurbaines**	
	Véhicules légers	Véhicules lourds	véhicules légers	Véhicules lourds
Admission	*	*		
Échappement	*	*	*	**
Bloc moteur	*	***		**
Boite de vitesse et transmission	variable			
Ventilateur		**		
Contact pneu/chaussée	* à **		***	*

* contribution importante, ** contribution très importante, *** contribution majeure

Les moteurs

Le niveau du bruit du moteur augmente en fonction de la vitesse, et un peu moins selon la cylindrée C du moteur, et nous pouvons dire qu'en principe le niveau total de bruit en dB(A) varie comme suit (réf. 4) :

Moteurs Diesel :	$L_A = 30 \log N + 17.5 \log C$
Moteur à allumage par étincelle :	$L_A = 50 \log N + 17.5 \log C$

Ces équations montrent que pour la même production d'énergie, un moteur à grande cylindrée fonctionnant à vitesse réduite serait plus silencieux qu'un moteur fonctionnant plus vite.

Le contact pneu/chaussée

Les résultats des premières études suggéraient qu'il y avait une certaine relation entre la résistance de la surface de la chaussée et la formation du bruit. Cependant, d'après les travaux menés en 1979, nous savons à présent que cette relation n'est vraie qu'en ce qui concerne chaque type particulier de revêtement de la route. Ainsi il n'y a pas de relation systématique entre l'épaisseur moyenne du revêtement et la formation du bruit.

Le bruit du roulement augmente rapidement avec la vitesse V du véhicule parce que la puissance acoustique totale qui est produite augmente comme une puissance de 3 à 4 de la vitesse. Ainsi nous avons pour le niveau maximum de bruit :

$$L_A = 30 \text{ à } 40 \log V + \text{ une constante}$$

Avec des pneus différents, le niveau de bruit pour une même route peut différer de près de 8 dB dans le cas de voitures, et de près de 12 dB pour les poids lourds.

Le bruit de roulement est dû à nombre de différents effets comme le montre le Tableau 5. Puisque la production de bruit est concernée, nous pouvons classer les textures des surfaces de chaussées selon la densité spectrale du profil longitudinal pour des longueurs d'ondes allant de 2 à 200 mm (réf. 5) . Si nous définissons le carré moyen des irrégularités de la surface par un éventail de longueurs d'ondes λ comme T_λ, alors le "facteur de texture" peut être exprimé ainsi :
$L_\lambda = 10 \log_{10} T_\lambda/10^{-12}$ où L_λ est exprimé en dB faisant référence au niveau 10^{-12} m^2. En utilisant le laser, il est maintenant possible de déterminer la puissance spectrale des densité du profil de chaussées avec un haut degré de précision et à bas prix. Les surfaces ayant un haut "niveau de texture" donnent lieu en particulier à une vibration du pneu et le phénomène de type I prédomine. Les surfaces ayant un 'niveau de texture' faible donnent lieu en particulier aux perturbations des types II et III.

Tableau 5. Bruit dû au contact pneu/chaussée

	Phénomènes	Caractéristiques de la surface de la route
I	Vibration verticale et rayonnement du bruit à partir de l'enveloppe du pneu	Profil longitudinal (macrotexture). Impédance mécanique au point de contact (propriétés élastiques de la route)
II	Aspiration et expulsion d'air (pompage d'air et résonance des poches d'air)	Géométrie et porosité.
III	Vibrations tangentielles dues à une succession d'adhérences et de glissements.	Propriétés physico-chimiques et profil longitudinal

L'importance de l'impédance de la surface de la route n'est pas très bien comprise : les surfaces de routes ayant une forte impédance mécanique (béton hydraulique ou vieux bitume) tendent à une émission plus importante de bruit que les surfaces où le bitume a été récemment répandu, quoique la différence du niveau de bruit ne se réduise en fait qu'à quelques décibels.

I.3. Les automobiles

Les automobiles sont en pratique les véhicules les plus silencieux du trafic urbain à l'exception de certaines voitures Diesel. Des réductions du niveau de bruit ont été atteintes par l'amélioration des moteurs et l'attention portée aux échappements. En Allemagne, le niveau ISO du bruit des taxis Diesel traités est passé de 80 dB(A) à 74 dB(A). L'encapsulage du moteur et des transmissions n'a généralement pas été nécessaire pour atteindre des limites de bruit ISO de 77 dB(A) ; en effet, il est vraisemblable qu'une cible un peu plus stricte d'environ 75 dB(A) pourrait être atteinte avec peu ou pas de pénalités.

Sur les voies rapides, les automobiles peuvent être plus bruyantes que les poids lourds, en raison du bruit de contact pneu/chaussée.

I.4 Les poids lourds

Le niveau de bruit des camions est fréquemment de 10 dB(A), plus important que celui des voitures en raison de leurs moteurs Diesels et de la puissance plus importante des moteurs ; mais il semble très probable que les réglementations des émissions de bruit réduiront cet écart (voir Tableau 3). En outre, les pratiques de livraisons juste à temps étant néfastes à l'environnement, la nécessité d'opérer de nuit et la législation pourraient inciter à l'introduction de poids lourds très silencieux.

Les moteurs et échappements des camions émettent du bruit en basse fréquence avec une intensité bien plus forte que les voitures. La propagation de ce bruit à travers l'air peut faire vibrer les fenêtres et parfois même les murs et sols des bâtiments les plus proches.

Pour les véhicules qui ne parviennent pas aux niveaux de bruit requis, les fabricants appliquent dans la plupart des cas toutes sortes de protections pour atteindre les exigences d'émissions actuelles des moteurs. Pour parvenir à des niveaux de bruit encore plus bas, ces véhicules sont aujourd'hui équipés de moteurs presque entièrement encapsulés. Les protections et enveloppes sont considérées comme des parties additionnelles ayant des désavantages : elles entraînent des problèmes de refroidissement du moteur, d'augmentation du poids, de maintenance et de coût.

La taille des silencieux associés au système d'admission et d'échappement du moteur est un problème dans la mesure où leur efficacité à basse fréquence dépend de leur volume.

L'expérience des différents programmes de poids lourds silencieux suggère qu'avec la production de moteurs silencieux, d'écrans acoustiques latéraux et de système d'atténuation importante du bruit des échappements, un maximum de poids lourds puisse atteindre un niveau de bruit en conditions ISO de 82 - 83 dB(A) (réf. 6). Avec une enveloppe partielle, le même véhicule peut atteindre 80 - 81 dB(A). L'encapsulage complet du moteur permet au véhicule d'atteindre des niveaux de bruit aussi bas que 77 dB(A) soit en dessous des niveaux limites actuels.

I.5 Transport public. Les autobus

Les désagréments que produisent les autobus peuvent être importants par exemple de nuit et/ou près des stations de autobus.

Généralement les moteurs de autobus sont des moteurs de camions. Des silencieux et des protections acoustiques peuvent être développés en peu de temps. Des moteurs complètement encapsulés avec refroidissement éloigné sont utilisés dans des autobus (et sur des véhicules spéciaux de livraison à faible bruit) en Allemagne. Les facteurs critiques peuvent être la disponibilité de techniques convenables et les conditions de maintenance. En Allemagne 90% des nouveaux autobus répertoriés ont des moteurs encapsulés (niveaux de bruit compris entre 77 - 82 dB(A)).

Des expériences très encourageantes ont été menées sur des autobus électriques : des trolleys sont utilisés dans beaucoup de villes. Quelques innovations mécaniques et électriques ont été développées depuis des années, particulièrement en Allemagne ou en Suède, mais les autobus électriques munis de batteries ou les lignes de trolley sont chers, comme le sont aussi les différents autobus hybrides munis de systèmes de récupération d'énergie.

II. LES TRAINS.

Les populations Européennes et Japonaises sont fortement soumises au bruit des trains, particulièrement dans les aires urbaines et dans les vallées (voir tableau 6).

Tableau 6. Exemples d'exposition au bruit ferroviaire en Europe (réf. 7)

Pays	Pourcentage de personnes exposées à un niveau de bruit excessif			
	55 dB(A)	60 dB(A)	65 dB(A)	70 dB(A)
Allemagne	13,0	5,0	1,0	
France	1,4	0,8	0,4	0,15
Suisse	20,0	11,0	4,0	1,0

II.1. Les sources du bruit ferroviaire

Le bruit des véhicules guidés provient d'une diversité de sources, dont le système de propulsion, l'interaction roue/rail et le bruit aérodynamique. Le système de propulsion tend à être le bruit dominant aux vitesses faibles, la traction électrique étant considérablement plus silencieuse que la traction Diesel ou à turbines. L'interaction roue/rail devient la source de bruit dominante pour des vitesses supérieures à 50 mph pour les trains électriques conventionnels. Pour les vitesses supérieures à 300 km/h, le bruit aérodynamique doit être considéré. Actuellement, le bruit dû au roulement tend à devenir de plus en plus la forme de bruit dominante.

Le bruit dû au roulement

Le bruit externe dû au contact entre les roues du train et le rail est le résultat d'un phénomène complexe. Des investigations expérimentales menées là où le bruit de roulement était présumé être dominant, ont montré que les niveaux de bruits peuvent être exprimés par le type suivant d'équation (réf. 8) :

$$L_{max} = 30 \log V + \text{une constante}$$

Les différences sont en partie dues à la façon dont le bruit a été mesuré (périodes d'intégration plus ou moins longues). Selon cette analyse qui prend en compte les vibrations forcées, la vitesse de déplacement du véhicule est impliquée dans l'émission de bruit pour trois raisons :

a) Gamme de rugosité. Connaissant la longueur d'onde λ des irrégularités ou du rail de la table de roulement des roues, la fréquence du bruit émis est donnée par $f = V/\lambda$ où V est la vitesse de déplacement du véhicule.
b) Filtrage de l'ellipse de Hertz. Ce filtre agit en fonction du nombre de longueurs d'onde k de la voie ou des roues.
c) Coefficient du niveau μ (V). Ce dernier terme exprime la variation de l'énergie injectée par unité de temps en fonction de la vitesse du véhicule. Approximativement cette énergie varie selon V^2.

L'usure des rails a cependant un rôle majeur autant pour les coûts d'entretien que pour le bruit des trains à très grandes vitesses (ce qui n'est pas le cas quand la sustentation magnétique est utilisée).

Pour des conditions roue/rail parfaites, l'analyse exposée semble inadéquate : à grande vitesse le bruit pourrait être émis principalement par les fréquences résonnantes de la vibration des roues et des rails (réf. 9). En conclusion, nous devons souligner que depuis 10 ans notre compréhension de la production de bruit dû au contact roue/rail a régulièrement progressé (réf. 10).

Le bruit aérodynamique

Avec l'arrivée du Train à Très Grande Vitesse, les sources de bruit aérodynamiques entrent en ligne de compte de façon brutale, puisque la vitesse dépasse les 250 km/h. Notre connaissance de l'aéroacoustique et les résultats des mesures confirment l'hypothèse d'un taux d'augmentation du bruit aérodynamique lié à la vitesse de 60 à 70 log V. Ces relations sont montrées sur la figure 1 pour des trains types. Les deux courbes s'appliquent à des trains conventionnels où la source roue/rail domine jusqu'aux vitesses de 150 - 200 mph, vitesses au-dessus desquelles le bruit aérodynamique devient significatif.

Le bruit aérodynamique est lié au coefficient de résistance aérodynamique du train (réf. 11). Certaines sources du bruit aérodynamique sont dues aux vortex créés par l'essieu, aux pantographes et aux éléments en surface tels les essuie-glaces. Les pantographes et les cavités sous les voitures sont les causes principales du

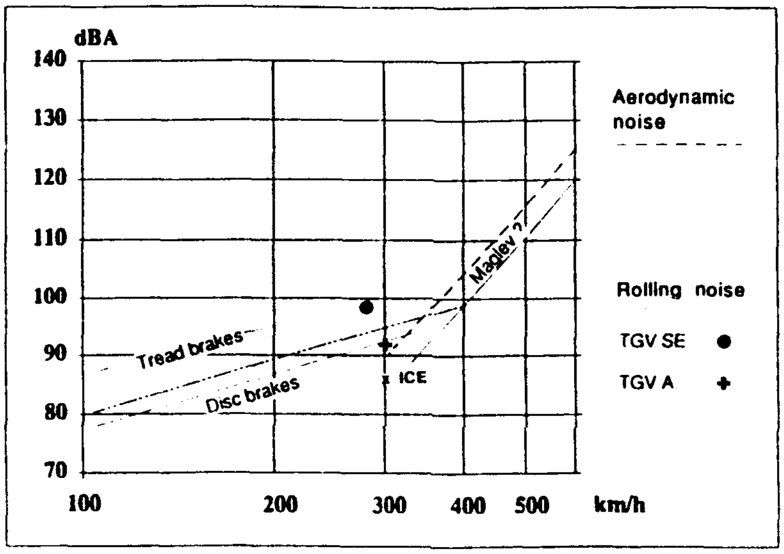
bruit aérodynamique. Des tests à échelle réelle sur ce problème sont menés dans des tunnels d'air anéchoïques, ainsi qu'avec des antennes pour mesurer le bruit lors des passages de trains.

Les véhicules à lévitation magnétique sont sujets aux mêmes conditions aérodynamiques que les autres trains, mais le Maglev qui n'a pas de pantographe pourrait être moins bruyant à grande vitesse et également à basse vitesse dans les aires urbaines (fig. 1). Les forces magnétiques oscillatoires créent un niveau de bruit comparable à ceux des trains à grande vitesse conventionnels. Actuellement, il n'est pas évident qu'à grande vitesse le Maglev soit plus silencieux que les T.G.V.

Les émissions de bruit des Trains à Grande Vitesse.

Sur la figure 1, les courbes de bruit sont indiquées pour certains trains roues - rail parmi les plus rapides ainsi que pour un système Maglev circulant sur une structure aérienne. Les données ont été relevées d'après des mesures ou des prévisions à une distance standard internationale de 25 mètres, correspondant à 75 pieds.

Figure 1. Niveaux de bruit de T.G.V. (roues et Maglev) à 25 m. de la voie.



La courbe bruit/vitesse illustre la combinaison des bruits roue/rail et aérodynamiques (réf.12). A des vitesses inférieures à 350 Kph pour le T.G.V., l'inclinaison de la courbe suit la relation *30 log.V* vue plus haut. Quand la vitesse atteint 350 Kph, l'inclinaison change graduellement pour correspondre à la somme des bruits roue/rail et aérodynamiques, et à une vitesse supérieure à 180 mph, l'inclinaison traduit la relation *60 log.V* du bruit aérodynamique.

II.2. Contrôle du bruit ferroviaire

La réduction du bruit ferroviaire pourrait provenir de la conception des véhicules ou des voies. Des changements des modes d'exploitation des trains tels que la diminution de la vitesse pourraient avoir un effet général peu rentable et seulement un avantage acoustique mineur. Par exemple, une réduction de 25 pour cent de la vitesse de 300 à 225 km/h pourrait seulement amener une réduction de 4 dB en niveau sonore maximum et 2.5 dB en Leq_A.

Le véhicule - Trois catégories de mesures peuvent être considérées (réf. 13):

I. Mesures de réduction du bruit roue/rail : bogies plus légers ; équipements pour fixer les voies sur les traverses avec d'autres coefficients de suspension ; roues élastiques ; écrans antibruit pour les bogies ; pièces plus légères pour le matériel roulant ; équipement de rectification de la surface de roulement et le rail ; détecteurs mobiles, etc.
II. Mesures défensives contre le bruit de captage d'énergie ; couverture pantographe du toit ; utilisation de moins de pantographes ; conception du pantographe améliorée ; graissage du câble d'alimentation ; lubrifiant solide des équipements.
III. Mesures défensives contre le bruit aérodynamique de la carrosserie : extrémités du véhicule plus lisses, amélioration de la forme arrière du train, etc.

'installation de jupes sur les roues n'est pas encourageante à cause de l'incapacité de protéger à la fois la oue et le rail. L'usage de roues élastiques s'est avéré pratique uniquement pour les trains à basse vitesse en aison de taux d'usure non acceptables. L'utilisation de véhicules articulés (et par là la réduction de moitié du ombre de roues) s'est avérée avantageuse avec les T.G.V.

e remplacement par des freins disques des freins à sabot amène une réduction importante du bruit de oulement (voir tableau 7) mais cela est difficil... ur les motrices par manque de place. Ce changement ourrait apporter une diminution important... bruit de motrice, bien qu'il reste à voir si les roues des otrices qui fonctionnent avec des freins à disque garderont leurs caractéristiques aussi bien que les autres.

Tableau 7. Bruit du T.G.V.

T.G.V.	Lmax-25m dBA	Vitesse commerciale (km/h)	Équipement
Paris - Lyon	99,0	270	Freins à sabot.
Atlantique et Paris Lille	91,5 - 94	300	Freins à disques pour les wagons de passagers.
Futur	inférieur à 3-4 ?		Des freins à disques supplémentaires sur les roues élastiques des motrices, couverts par le wagon.

a voie - Les niveaux de bruit diminuent si la distance des voies augmente, tombant typiquement de 4 à 6 dB haque fois que la distance est doublée mais le moyen de réduction le plus efficace pour le moment est installation de barrières ou d'écrans le long de la voie Une barrière absorbante de 2 m de haut réduira les iveaux de bruit de plus de 10 dB. Les tranchées ont autant d'effet qu'une barrière artificielle, et sont peut-tre plus acceptables pour la vue. Passer le long des voies de chemin de fer ou des autoroutes existantes, omme les lignes TGV-Atlantique et T.G.V. Paris-Europe du Nord, réduirait la gêne à un "couloir de bruit" xistant.

.a nouvelle ligne T.G.V. Atlantique ouverte en 1989, transporte des passagers entre Paris et l'ouest de la rance à une vitesse commerciale de 300 km/h. Une prédiction complète du bruit le long de la voie a amené à a construction de 11 000 m de bermes en terre, 17 800 m de barrières antibruit. Quelques maisons ont été solées. Les barrières antibruit sont généralement faites en béton ordinaire.

Ine protection complète de l'environnement peut ajouter des coûts importants à une nouvelle ligne à grande itesse, de 25 pour cent sur le "Neubraustrecken" allemand à peut-être 40 pour cent pour la liaison au tunnel ous la Manche proposée dernièrement par les chemins de fers britanniques.

.a technologie et l'expertise sont maintenant disponibles pour fabriquer une ligne ferroviaire à grande vitesse cceptable du point de vue de l'environnement, mais pour une vitesse supérieure à 350 km/h, la source rincipale étant le bruit aérodynamique, des barrières acoustiques très hautes devraient être nécessaires, elles-ci pourraient s'avérer impossible pour les raisons environnementales, de confort et de coût, pouvons-ous envisager des barrières transparentes ? Quelques décideurs japonais semblent croire qu'il doivent limiter a vitesse des trains rapides à 320 km/h à cause de l'énorme difficulté de la diminution du bruit érodynamique.

1.3 Transport guidé urbain

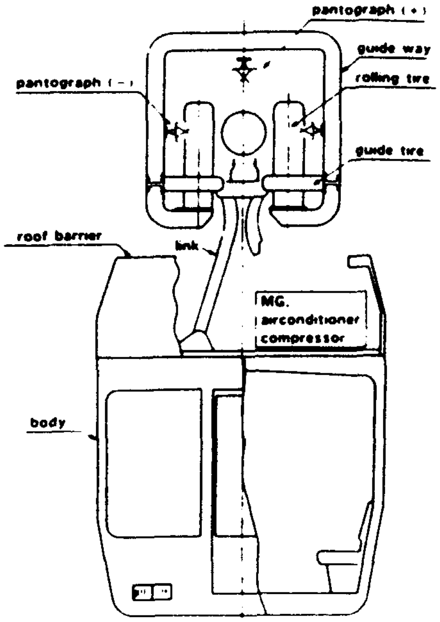
.e contrôle du bruit ferroviaire aérien peut être assuré par des barrières antibruit basses. En général des iveaux de bruit très bas sont obtenus avec ces divers systèmes qui sont propulsés électriquement. De plus, eaucoup de voies ferrées aériennes à petite vitesse sont équipées de pneus.

'our les monorails suspendus la diminution du bruit doit être obtenue à la source, à Chiba, dans la banlieue le Tokyo, par exemple, le niveau de bruit à une distance de 10 m de la voie du monorail est inférieur à 70 lB(A) (réf. 14), la figure 2 montre les dispositions des sources. Plusieurs techniques pour des réductions du ruit de chaque composant ont été utilisées :

Mesures pour la réduction du bruit (réf. 14)

Composants	Mesures
Bogie	Réduit la vitesse du moteur directeur. Améliore l'exactitude de l'embrayage. Renforce la boite de vitesse. Applique le matériel de refroidissement au cadre.
Pneu	Change le modèle nervuré traditionnel en lisse
Pantographe	Baisse le bruit du patin
Compresseur	Barrières sur le toit du véhicule.
Guides	Applique l'absorption de bruit et le matériel de refroidissement.

Figure 2. Sources de bruit d'un véhicule monorail (réf. 14)



III . L'INFRASTRUCTURE ET LA CIRCULATION ROUTIÈRE

Le bruit de la circulation dépend du site, de la route ou de la chaussée et des émissions sonores des véhicules; pour une circulation fluide constante le Leq_A est largement défini par les types de formules suivantes :

LeqA=	Paramètres
Cte +	Type de véhicule
Cte +	Surfaces de la route et des roues
$10 \log(Qvl+EQpl)$ $+20 \log V$	Trafic
$-12 \log d+10 \log \theta$	Site

Les formules montrent la part du site et la part de la circula...

- **Qvl, Qpl** : nombre de véhicules légers (<3,5t) et de poids lourds (>3,5t) par heure
- **E** : facteur équivalant acoustique entre véhicules légers et poids lourds
- **V** : vitesse
- **d** : distance de la route
- **θ** : angle sous-tendu par le carrefour à partir du point de réception

III.1 Surfaces routières silencieuses

Par l'utilisation d'une surface de chaussée poreuse il est en principe possible d'obtenir une diminution du Leq_A d'approximativement 3 à 6 dB(A) pour une circulation routière à des vitesses supérieures à 70 km/h. La réduction du niveau de bruit maximum Lmax pourrait atteindre 7 dBA. Pour les routes et les rues à vitesse réduite les surfaces s'encrassent avec le temps et la réduction du bruit est abaissée à 0 à 1 dB(A) en à peine une année : les types de surfaces poreuses les plus évoluées sont requis, tels que les multicouches ou les couches très épaisses, ou encore des couches à porosité très élevée.

Pour l'enrobé ouvert avec des liants en caoutchouc et en bitume, il n'y a pas besoin de sable et de ce fait l'enrobé est moins coûteux et le pourcentage du volume des trous d'air peut atteindre 30 % (généralement le pourcentage est de 20 %). Il pourrait donner une réduction de bruit de 5-10 dB(A), mais à ce jour plusieurs problèmes non acoustiques sont encore en suspens.

Dans la plupart des cas, la résistance réduite de l'enrobé poreux peut amener des coûts représentant plus de 1,5 à 5 fois le coût conventionnel des surfaces routières et il y a aujourd'hui (réf. 15) un défi pour l'utilisation de l'enrobé ouvert pour les voies urbaines où les surfaces routières sont fréquemment détruites par les travaux publics, mais, dans quelques cas les propriétés de réduction du bruit de l'enrobé poreux permettent de se passer de barrières acoustiques et de ce fait d'obtenir un rapport coût/efficacité positif.

III.2 Écrans

Dans la zone protégée du bruit derrière une barrière, la réduction du bruit est généralement supérieure à 10 dB(A) si la barrière est suffisamment longue et s'il n'y a pas de réflexion sonore parasite. Ainsi pour les zones à densité faible ou moyenne, les barrières antibruit sont largement utilisées en Europe. Ces barrières peuvent être : des talus, des panneaux de bois, de verre ou de métal, des murs. La plupart des barrières européennes sont réfléchissantes et plutôt économiques; soit la réflexion est inoffensive avec la barrière verticale, soit la forme de la barrière évite des réflexions nuisibles ; la solution habituelle est trouvée en inclinant à la verticale l'écran antibruit existant - un angle d'inclinaison de 5 à 10 ° est habituellement suffisant. L'intrusion visuelle est le principal problème. Pour les autoroutes élevées, des petits parapets peuvent réduire les niveaux de bruit de 12-15 dB(A) pour les bâtiments riverains les plus bas.

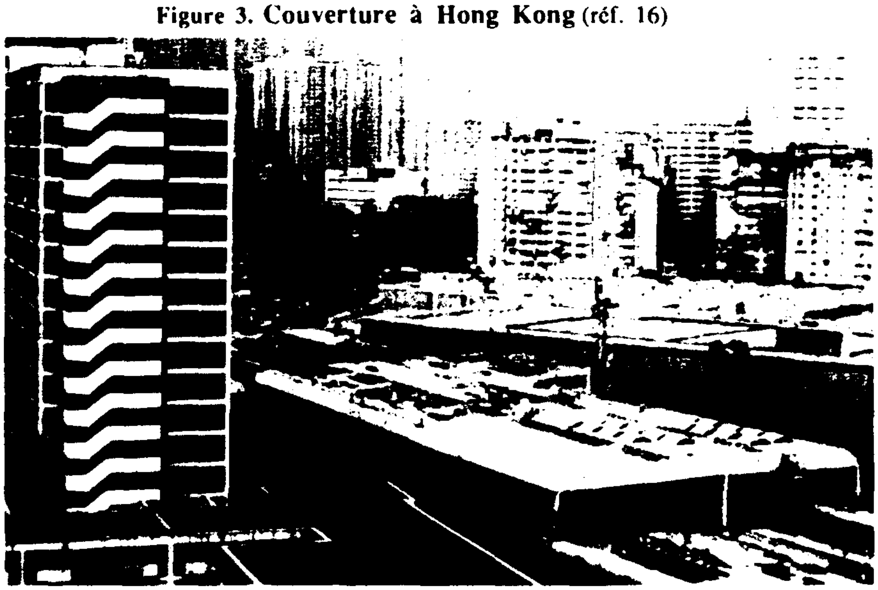
Outre leurs qualités acoustiques (en particulier une masse minimum par surface unitaire), les écrans antibruit doivent pouvoir supporter les effets du vent, être de construction durable, être faits de matières ininflammables et avoir une apparence acceptable. Les exigences en sécurité amènent également au besoin de situer les écrans à une distance minimum des barrières de sécurité, cette distance dépend du degré auquel de telles barrières peuvent être déformées en cas de choc (une distance de dégagement de 1,5 mètres est généralement demandée). Une exception à cette exigence de dégagement apparaît en cas de structures qui servent à la fois pour les écran antibruit et les barrières de sécurité.

Les écrans absorbants sont coûteux et parfois employés en Europe ou aux USA. Au Japon, les barrières absorbantes sont utilisées le long des autoroutes, leur intrusion visuelle est diminuée par leur uniformité dans le pays. Les matériaux employés pour les écrans absorbants le bruit doivent avoir un coefficient d'absorption Sabine d'à peu près 0,6 sur une bande de fréquence de 250 à 2,000 Hertz. Les capacités d'absorption du bruit ne doivent pas être affectées par les agressions climatiques ou par le rayonnement solaire et il ne devrait pas y avoir le risque que les matériaux absorbants composants l'écran s'obstruent et s'encrassent par la poussière. La partie absorbante de l'écran peut être composée de fibre poreuse, telle que la laine de verre, etc., protégée par une tôle perforée ou un panneau poreux couvert d'une plaque en matière plastique pour empêcher le colmatage par la poussière. Le coût peut monter jusqu'au double du coût des écrans réfléchissants types.
D'une façon plus générale, des matériaux absorbants sont employés en cas d'implantations où il y a une protection contre les intempéries comme les tunnels, les routes couvertes et les systèmes de métros souterrains.

III.3 Couverture partielle et enceinte totale

Dans les zone à forte population avec des bâtiments élevés, l'implantation des infrastructures en tunnels ou une couverture totale ou partielle peuvent diminuer le bruit de 30 à 10 dB(A), mais ces moyens sont très coûteux. Dans les zones urbaines en particulier, les routes et les métros souterrains sont souvent la seule solution acceptable pour l'environnement. Un encapsulage total de la route par un écran solide est peut-être la solution ultime pour la pollution due au bruit routier. Au centre ville la couverture totale permet l'organisation des activités urbaines sur de multiples niveaux.

Figure 3. Couverture à Hong Kong (réf. 16)



Il y a plusieurs exemples à Hong Kong (réf.16) et en Allemagne. La couverture totale est coûteuse pour la ventilation et l'éclairage, la couverture partielle ne l'est pas. La recherche s'est concentrée sur la conception de couvertures avec des ouvertures en général sous forme de grillage en lames ou de séries de lucarnes ; la réduction du bruit peut atteindre 15 dB(A), mais le besoin d'un revêtement d'absorption du bruit sur les lucarnes ou les grillages en lames a été démontré (réf. 17).

IV. BÂTIMENT ET ORGANISATION URBAINE

IV.1 Isolation des bâtiments

L'industrie du bâtiment fabrique des panneaux et des fenêtres efficaces pour l'isolation sonore et thermique. La crise de l'énergie contribue en quelque sorte à ces améliorations acoustiques des bâtiments mais on doit faire la distinction entre les caractéristiques acoustiques et thermiques des parties du bâtiment.

La rénovation des zones de construction de vieilles tours longeant les voies rapides en banlieue est pratiquée en France : par exemple dans la ville de BRON, 2 000 logements ont été améliorés de 1981-85 du point de vue acoustique, thermique et visuel. L'opération a été réussie mais le bruit de voisinage est devenu plus perceptible et a engendré des plaintes !

Au Danemark, aujourd'hui à peu près 10 % de tout le parc de logements a été construit en considérant les exigences du bruit.

IV.2 Intégration autoroutes - bâtiments

Le remodelage des zones à urbaniser et à construire le long des voies rapides qui traversent les zones urbaines dépend beaucoup du besoin de protection contre le bruit. Les deux possibilités extrêmes de l'utilisation du terrain le long des routes sont l'éloignement des bâtiments de la route ou une intégration totale de la route et du bâtiment.

L'éloignement n'est pas très efficace tant que la route reste en ligne de vision directe de la zone prise en considération, car la distance doit être doublée pour obtenir une atténuation de 3 dB(A).

Dans les zones constructibles à haute densité d'occupation, la construction de bâtiments très proches ou au-dessus de l'infrastructure rend possible la protection des zones résidentielles et donne à la voie une signification urbaine. Le gaspillage de terrain, le bruit de fond, la fragmentation de l'espace de la ville seraient ainsi réduits.

IV.3 Centres ville, zones résidentielles, limitations de vitesse

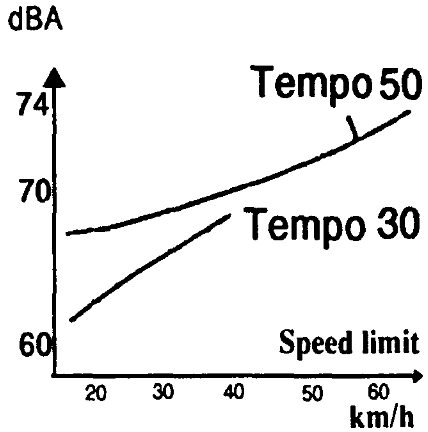
L'interdiction des voitures particulières en zones urbaines apparaît dans de nombreuses villes européennes. Les autorités locales pourraient aussi beaucoup améliorer l'environnement dans les zones résidentielles par des actions détaillées sur les voies d'accès. Les feux de signalisation, les facilités de stationnement, la peinture sur chaussée, la clôture partielle de quelques rues etc. peuvent diminuer les vitesses et exclure les traversées inutiles. Ces concepts intéressants sont appliqués en Europe du Nord, Italie etc. (réf. 18).

L'efficacité acoustique de ces restrictions de trafic dépend du pourcentage de véhicules restants. A Rome par exemple, les réductions de bruit sont restées faibles, de 3 à 5 dB(A) à cause de l'augmentation respective de la vitesse du trafic et de la circulation des autobus (réf. 19).

La modification des limitations de vitesse peut aussi influencer le style de conduite. Par exemple, en Allemagne de l'Ouest dans les années 1970, on a trouvé qu'après que la limitation de vitesse eut été changée de 50 km/h à 30 km/h sur des voies urbaines (Tempo 30 en FRG), les niveaux de bruit étaient partiellement réduits, comme prévu, par les limitations de vitesse de la circulation mais aussi à cause de changements au style de conduite adopté (fig. 5, réf. 20) les conducteurs accéléreraient et décéléreraient moins agressivement que lorsqu'ils conduisent sur une voie avec une limitation de vitesse supérieure. La réduction du bruit Leq_A attribuable aux changements du comportement du conducteur se situait entre 2-4 dB(A) dépendant de la vitesse effectivement atteinte

Il est aussi nécessaire d'envisager les niveaux de pointe du bruit et pas simplement le Leq, en particulier la nuit. Les résultats des différentes études reportent une réduction de 5 dB(A) à 6 dB(A) des niveaux de bruit de pointe (correspondant à ce qui pourrait être atteint en encapsulant les moteurs de véhicules).

Figure 5. Effet de la limitation de vitesse sur le bruit automobile



V. DEUX TECHNIQUES POUR LE FUTUR

V.1. Contrôle actif du bruit

Le principe du contrôle actif du bruit est l'interférence destructrice d'un champ sonore indésirable avec un champ de contrôle généré par des sources actives complémentaires. L'avantage du contrôle actif du bruit provient de ses potentialités pour réduire les poids, tailles, et coûts des systèmes de protection contre le bruit exigées par les techniques classiques de protection passive du bruit, qui d'ailleurs sont en général - comme les silencieux et les barrières antibruit - pas très efficaces en fréquences basses (1 600 références sur le contrôle actif du bruit sont aujourd'hui trouvées dans la bibliographie). Inversement, les contrôles actifs sont souvent plus efficaces en fréquences basses. Les applications actuelles du transport associent généralement l'industrie aéronautique et le confort interne du véhicule routier. Dans le domaine environnemental, les points suivants devraient être envisagés dans un lointain futur :

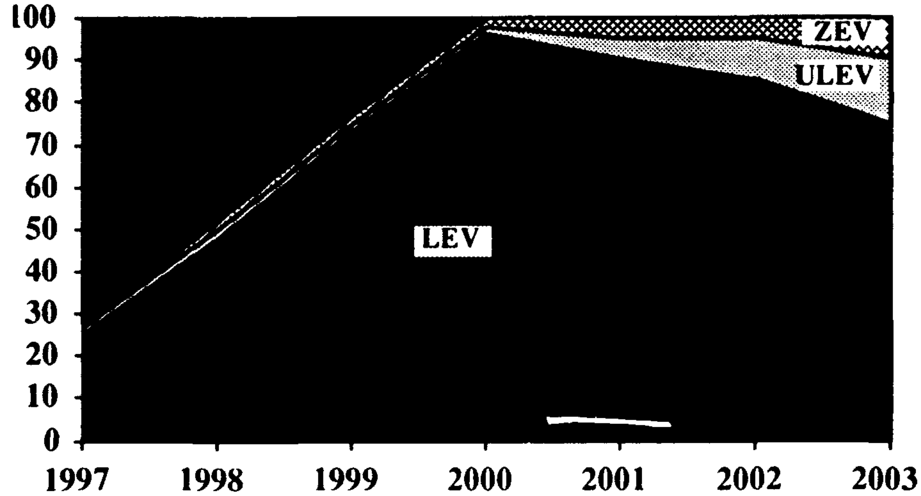
1 - l'insonorisation des véhicules, en particulier par les systèmes de silencieux électroniques dans lesquels un système de contrôle est branché à l'arrière de l'échappement du moteur et améliore à la fois l'émission acoustique et le rendement du moteur,
2 - des cas où des sources actives peuvent être installées près de la source émettrice du bruit (les sources de bruit étendues sont difficiles à maîtriser),
3 - des zones fermées telles que places ou "piazettas" où la mise en pratique du contrôle actif du bruit est plus facile que dans les zones ouvertes,
4 - des configurations acoustiques des fenêtres de bâtiment mais les expériences à ce jour s'avèrent trop coûteuses et décevantes.

V.2. Les véhicules électriques

Le moteur à hydrogène est aussi bruyant que le moteur classique à combustion interne et le stockage n'est pas très facile. Le lent développement des accumulateurs électriques a souvent été démoralisant mais dans le 21ème siècle, les véhicules électriques seront probablement d'un usage commun dans quelques zones urbaines. Les accumulateurs permettent déjà un grand nombre de trajets urbains à une vitesse de 30-50 km/h, recommandés par les défenseurs de "la circulation apaisée". La conduite silencieuse à des vitesses basses ne peut être obtenue qu'en utilisant l'énergie électrique.

Les autorités du bassin de la côte sud dans la région de Los Angeles ont décidé l'introduction progressive des véhicules à émission zéro, ce qui veut actuellement dire véhicules électriques (fig. 6). Un appel d'offre a été lancé pour 10 000 véhicules.

Figure 6. Programme de Los Angeles de 1997 à 2003. Proportion de véhicules classiques (type US 1992) - Véhicules à basse émission (LEV) - véhicules à émission très basse (ULEV) véhicules à émission zéro (ZEV)



Deux cas de véhicules électriques devraient être distingués :

1) Le cas des véhicules électriques classiques développés sur la base des véhicules classiques ou les très petits véhicules (voiturettes françaises). Dans quelques pays, les accumulateurs et les moteurs électriques sont simplement mis en service sur des sous-châssis de véhicule classique.

2) Le cas des véhicules initialement conçus pour fonctionner électriquement. Par exemple des voitures spécialement développées pour utiliser des moteurs électriques dans les roues sont fabriquées avec un coefficient Cw de résistance aérodynamique excellent de 0.19 qui peut être expliqué par la baisse de la hauteur du véhicule due à l'absence de tuyauterie d'échappement et de pont.

Les constructeurs de véhicules classiques du monde entier présentent des prototypes de véhicules électriques. Des véhicules "Hybrides" équipés de moteurs électriques et thermiques qui permettent une opération urbaine écologique et des voyages routiers habituels, semblent coûteux en ce qui concerne la fabrication et l'entretien. En France, la spécialité de la "voiturette" mène à de nombreuses présentations de très petits écovéhicules mus électriquement.

Quand la vitesse dépasse 40-50 km/h, le véhicule électrique est aussi bruyant qu'un véhicule thermique puisque l'émission de bruit est alors due aux pneus. Ainsi le développement des véhicules électriques pourrait favoriser les recherches pour le développement de pneus non bruyants.

Dans les villes, la surface de chaussée, les tunnels et les alternatives en passages souterrains impliquent actuellement des coûts élevés de construction et d'exploitation pour l'extraction des gaz pollués et, il est clair que dans un lointain futur les véhicules électriques seront très intéressants à ce point de vue.

CONCLUSIONS.

La pollution due au bruit dans les villes est causée essentiellement par le réseau routier actuel. Différentes méthodes ont été développées pour la réduction de ce bruit et les concepteurs de véhicules, les ingénieurs routiers, les planificateurs urbains et les architectes doivent travailler ensemble pour la suppression du bruit.

Néanmoins si nous excluons quelques rares villes nouvelles, obtenir une tranquillité satisfaisante dans toutes les zone urbaines consitue une tâche très difficile. Les émissions de véhicules routiers seront réduites de 5 dB (A) en 10 ans, quelques véhicules électriques seront utilisés dans des buts spécifiques, mais l'évolution croissante de la mobilité et les perspectives de développement pour les nouvelles infrastructures vont sûrement mener à une augmentation importante dans les nuisances sonores dues au transport malgré les lois sur les émissions de bruit du véhicule mises en application depuis les années 70.

Pour le long et moyen terme, les moyens destinés à réduire la mobilité et à favoriser le transfert des automobilistes vers les systèmes de transport collectifs ou non motorisés peuvent être mis en question ; mais il est clair que favoriser la circulation des véhicules automobiles comportera à terme des risques importants de détérioration de la qualité de l'environnement. Des mesures sévères seront destinées à limiter l'utilisation de véhicules bruyants dans les villes, à réorganiser la circulation des véhicules légers et des poids lourds, de nuit comme de jour.

A long terme, le contrôle actif du bruit devrait être considéré aussi bien pour les véhicules que pour les espaces extérieurs. Les accumulateurs actuels de véhicules propulsés électriquement permettent déjà d'assurer un nombre important de trajets urbains à la vitesse de 30 km/h. Ceci pourrait fournir les conditions d'une "circulation tranquille" dans les zones résidentielles urbaines et une coexistence paisible des divers usagers de la route non motorisés.

L'organisation de plans d'aménagement publics et privés pour les zones à urbaniser le long des infrastructures de transport peut permettre de trouver des solutions plus économiques et plus environnementales que les moyens palliatifs actuels (distance, écrans, etc.). Une planification urbaine dynamique serait la façon la plus rationnelle d'éviter l'apparition d'une nouvelle pollution due au bruit. Les municipalités doivent poursuivre un urbanisme plus actif, dans lequel considération est donnée à toutes les conditions environnementales, telles que le bruit, la pollution atmosphérique, les accidents, l'intrusion visuelle etc.

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Noise-Induced Hearing Loss

Introduction

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Noise & Man is the title of the sixth session of the International Commission on Biological Effects of Noise. Twentyfive years have passed since the first session.

One would assume that in such a timespan the problem of Noise-Induced Hearing Loss, NIHL, would have been possible to solve and that we would be able to see a reduction of the prevalence of NIHL. This is not the case. We still face the problem of new cases of NIHL and new aspects of the problem are showing.

When planning this meeting we started with the priorities from the ICBEN meeting in Stockholm in 1988. A revision of this list was done and it was decided to have presentations with more overviews and with practical implications.

Parallel to this series of meetings with ICBEN, a group of researchers on the initiative of Don Henderson in Buffalo have gathered every 5th year and have presented the progress in research achieved during the period. It is apparent that this series of symposia has greatly contributed to the progress seen mainly in basic research on NIHL. Two of the invited talks are given on parts of the basic research.

In this context it is important to give an emphasis on the workshop on "Central control of Auditory system Vulnerability to Noise Exposure" held at this meeting.

The current international Damage Risk Criterion - DRC - ISO/DIS 1999 was accepted some years ago as an acceptable criterion for the relation between noise exposure and the resulting damage. It must be one of the major objectives for the team to continuously have a control possibility to what extent the criterion is valid. Two of the invited papers are covering this issue.

Military noise should not easily be defined as work professional noise. However military noise, worldwide affects a lot of people and can no longer under peaceful conditions be accepted to influence the hearing of the exposed subjects. DRC's for military noise is therefore a topic of great interest and importance for this team.

Adequate Hearing Conservation Programs -HCP- constitute the basis for implementation of our knowledge from the DRC of the relation between exposure and damage. Since Noise-induced damage to the hearing is not an acceptable work environment factor, the HCP have to be efficient.

The topic of hearing protection partly belongs to the category of HCP. In all, we have two papers covering this important field.

When new knowledge and new data become available, it is necessary to continuously upgrade existing concepts and criteria in order to facilitate progress and to diminish Noise-Induced Hearing Loss. The repetition of this meeting every fifth year facilitates this concept.

Les pertes d'audition dues au bruit

Introduction

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Noise and Man est le titre de la 6ème session de la commission internationale sur les effets biologiques du bruit. 25 ans ont passé depuis la 1ère session.

On aurait pu penser que dans un tel laps de temps, le problème des pertes auditives dues au bruit serait résolu et qu'on verrait une diminution de la prévalence.. Ce n'est pas le cas. Nous sommes toujours devant de nouveaux cas et de nouveaux aspects du problème apparaissent.

Pour préparer ce congrès, nous sommes partis des priorités définies à Stockholm en 1988. Une révision de cette liste a été faite et il a été décidé de présenter des conférences donnant plus de vues d'ensemble et de débouchés pratiques.

Parallèlement à cette série de réunions de l'ICBEN, un groupe de chercheurs s'est réuni tous les 5 ans à Buffalo, à l'initiative de Don Henderson, et a présenté les progrès de la recherche réalisés pendant cette période. Il est évident que cette série de symposiums a beaucoup contribué aux progrès enregistrés dans la recherche fondamentale sur les pertes d'audition dues au bruit. Deux des conférences invitées sont basées sur cette recherche fondamentale.

Dans ce contexte, il est important d'attirer l'attention sur les travaux menés au cours de ce congrès sur l'atelier "Contrôle central du système auditif : vulnérabilité au bruit".

Le critère international de risque de dommage DRC-ISO/DIS 1999 a été adopté il y a quelques années comme un critère acceptable pour établir la relation entre exposition au bruit et dommage. Le groupe de travail doit avoir pour objectif essentiel de contrôler continuellement la validité de ce critère. Deux des conférenciers invités traitent de ce sujet.

Les bruits militaires ne peuvent pas être définis simplement comme des bruits professionnels. Ils affectent la santé de beaucoup de personnes et, en temps de paix, on ne peut plus accepter qu'ils détériorent l'audition des sujets exposés. Le critère de risque pour les bruits militaires est par conséquent un sujet important pour ce groupe de travail.

Des programmes de conservation de l'audition constituent la base de la mise en oeuvre de notre savoir sur les risques entre exposition au bruit et dommages. Les pertes d'audition n'étant pas un facteur d'environnement au travail acceptable, ces campagnes doivent être efficaces.

Le thème des protecteurs auditifs fait partie partiellement de ce sujet "campagnes d'information". En tout, nous avons deux articles couvrant cet important domaine.

Lorsque de nouvelles connaissances, de nouvelles informations deviennent accessibles, il devient nécessaire de constamment réévaluer les concepts et les critères existants pour faciliter les progrès et diminuer les pertes d'audition dues au bruit. Le retour de cette conférence tous les 5 ans nous aide dans cette tâche.

NOISE-INDUCED HEARING LOSS FROM DAILY OCCUPATIONAL NOISE EXPOSURE; EXTRAPOLATIONS TO OTHER EXPOSURE PATTERNS AND OTHER POPULATIONS

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During the last decades considerable efforts have been made to reduce occupational noise exposures. The contrary has been the case for most non-occupational noise exposures, such as exposure to environmental noise, traffic noise while travelling, noise from indoor sources and noise during leisure time. In this paper it is shown that the model from ISO 1999, that was developed for occupational exposure, can also be applied to estimate noise-induced hearing loss from non-occupational noise. Differences between occupational and the various non-occupational exposure situations are taken into account. Important factors in this respect are impulse noise, asymptotic threshold shift and duration of exposure during day and night.

1 Introduction

Today there is sufficient information about noise, its harmful effect on hearing and how to prevent noise-induced hearing loss to eliminate in principle the development of hearing loss due to occupational noise. During the last decades considerable efforts have been made to abate occupational noise and to prevent noise-induced hearing loss from occupational noise sources. In the Netherlands, for instance, the percentage of workers exposed to industrial noise with equivalent sound levels over the workday of 90 dB(A) or more is estimated to have decreased from 23% in 1975 to 10% in 1985 (Passchier-Vermeer, 1993). However, I do not intend to mean that in practice all occupational noise problems have been solved. For instance, in the Netherlands still 50% of the industrial workers are exposed to potentially hazardous equivalent sound levels over the workday of 80 dB(A) or more, and also in other occupational situations this seems to be applicable. But given also the fact that nowadays in most countries legal requirements concerning occupational noise exposure do exist, it is believed that we are going in the right direction.

Yet, while occupational noise exposure seems to be more or less under control, this appears to be quite the contrary for some types of non-occupational noise exposures. For instance, the pop-music phenomenon seems to be exploring new dimensions in house parties and car stereo's. In this paper the interesting question, why people expose themselves voluntary to such very high sound levels, will not be dealt with. This paper is limited to a view on the acoustical aspects of these exposures and the question how to rate them.

2 Occupational noise exposure

The second edition of ISO 1999 (ISO, 1990) allows to calculate hearing threshold levels of populations exposed to noise during working hours. Noise exposure is characterized by the equivalent sound level normalized to an eight hour working day ($L_{EX,8h}$). This implies that the model is based on the assumption of equivalent sound energy over a working day. Statistical relations are given between $L_{EX,8h}$ and noise-induced permanent threshold shift (NIPTS, N) for frequencies in the range from 500 to 6000 Hz and for exposure times of 1 to 40 years. NIPTS is largest at the frequency of 4000 Hz. In figure 1, percentile distributions of NIPTS at 4000 Hz and an exposure time of 40 years are given. NIPTS after an exposure time of 10 years is about 75% of the NIPTS-values given in figure 1 and after one year of exposure about 25% of these values. Below the 5th and above the 95th percentile the distributions should be considered as extrapolations from ISO 1999.

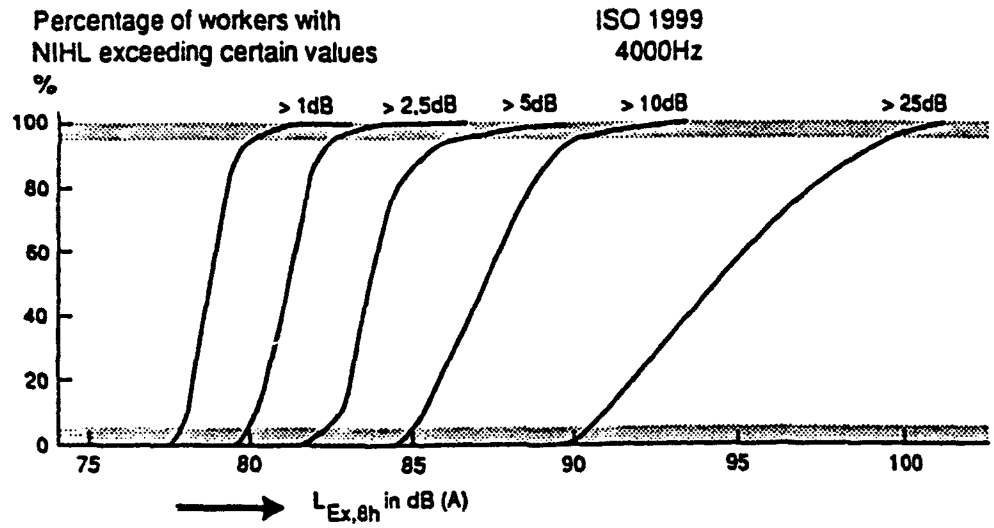

Figure 1. Percentage of people with noise-induced permanent threshold shift at 4000 Hz exceeding certain values as a function of the equivalent sound level during the workday. Exposure time is equal to 40 years.

Figure 1 shows that the probability of noise-induced permanent threshold shift is negligible below equivalent sound levels over the workday of 8 hours of 75 dB(A), also for very prolonged exposures.

The relations in ISO 1999 have been based on occupational noise exposures for about 8 hours a day. The results of an investigation by Axelsson (Axelsson, 1986) on the hearing of fishermen and coastguards showed the relations to hold also for much longer exposure times than 8 hours a day. The fishermen were usually exposed for 16 hours a day to an equivalent sound level of 90 dB(A) and their noise-induced hearing losses corresponded very well to those from exposure to an $L_{EX,8h}$-value of 93 dB(A).

During the Fifth Congress on Noise as a Public Health Problem I could show from an analysis of 56 occupational noise exposed (sub)populations that the median hearing thresholds agree very close to the values predicted in ISO 1999. This conclusion holds for $L_{EX,8h}$-values from below 80 dB(A) to over 100 dB(A), irrespective whether the noise contained impulse/impact components or not. The hearing threshold levels, just not exceeded in 10% of the workers of the populations appeared to be somewhat larger than predicted by ISO 1999; the small discrepancy observed was considered negligible for practical purposes (Passchier-Vermeer, 1990).

3 Non-occupational noise exposure

Noise exposure outside the workplace can be divided into the following, sometimes somewhat overlapping, categories:

- exposure to environmental noise in the living environment: traffic, industrial and residential noise;
- exposure to noise from traffic while travelling;
- noise at home;
- noise during leisure time.

Environmental noise

In principle these exposures may occur during the complete 24 hour period. For traffic noise, the equivalent sound levels during day-time are usually 8 to 10 dB(A) higher than during night-time. For the Netherlands it can be estimated that about 4% of the dwellings have equivalent sound levels over the 24 hour period, measured in the front of the houses, of 60 dB(A) or more due to traffic

noise (calculated from RIVM, 1988). Taking into account the sound insulation of dwellings, the time of the day spent in- and outside the house and the habits concerning opened and closed windows, the actual exposure during 24 hours due to traffic noise while at home is estimated to be more than 55 dB(A) in no more than 4% of the people.

Residential noise, such as from neighbour's domestic appliances, tools, musicplayers, noise from slamming car-doors, children playing in the neighbourhood, do not seem to contribute to any extend to the total daily noise exposure.

Noise while travelling

In travelling through large and medium-sized cities people are exposed to equivalent sound levels of 70 to 75 dB(A), virtually irrespective of the kind of transport used (Sone, 1990; Passchier-Vermeer, 1989). Equivalent sound levels while travelling in the countryside are less, except for people using motorbikes and motorcycles. For those people, equivalent sound levels of up to 100 dB(A) (under their helmet) have to be considered, dependent upon their speed and to a lesser extend upon the condition of their means of transport.

Noise while at home

Many noise sources contribute to the daily noise dose at home: domestic appliances, tools, TV, radio, musicplayers. One source should be explicitely mentioned: children. All these noise sources together leave an average housewife (or houseman) with an equivalent sound level during the day of 65 to 70 dB(A) (Sone, 1990, for comments see Passchier-Vermeer, 1993).

Noise during leisure time

Three sources and situations with high noise levels can be distinguished:

- popmusic
- loud games and sports
- children's toys.

Since the 60s the pop-scene has increased enormously. Nowadays there appear five main situations in which especially young people are exposed to popmusic: at popconcerts, in discotheques, at home listening to musicplayers with or without headphones, listening through headphones from portable equipment and while playing in an amateur-popgroup. Apparently many (combinations of) exposures and exposure times may occur. At any case, all exposures are of an intermittent nature.

This is also applicable to loud games and sports, such as shooting, e.g. hunting and target practice, motor sports, such as racing cars and mopeds/motorcycles, using model airplanes and tractor pulls and games such as arcade games, fireworks and staying in football arenas.

Also the very young children are sometimes exposed to high noise levels. Their squeaking toys are reported to produce equivalent sound levels at a distance of 10 cm of 78 to 108 dB(A). Moving and stationary toys produce at the same distance also about these levels. For toy weapons and firecrackers peak sound pressure levels at a distance of 50 cm of up to 155 dB have been reported. For comparison purposes, in the occupational situation, peak sound pressure levels are not allowed to exceed 140 dB according to the regulations in the European Communities.

4 Rating of non-occupational noise exposure

Since the model given in ISO 1999 for occupational noise exposure is the only generally accepted model for noise-induced hearing loss, it seems advantageous to consider whether this model could also be applied to non-occupational noise exposures. If ISO 1999 would be applicable to the 24 hour non-occupational noise exposures, then a difference of 5 dB(A) between the equivalent sound level during an 8 hour occupational noise exposure and a 24 hour non-occupational noise exposure should be taken into account. The onset-level for noise-induced hearing loss is then equal to an equivalent sound level of 70 dB(A) over 24 hours.

The main differences of non-occupational noise, as described above, compared to occupational noise, are:

a a larger variation in noise sources and exposure times from day to day
b usually lower background levels between noise exposures
c other populations, such as children and the elderly, are also exposed
d appreciation of the noise.

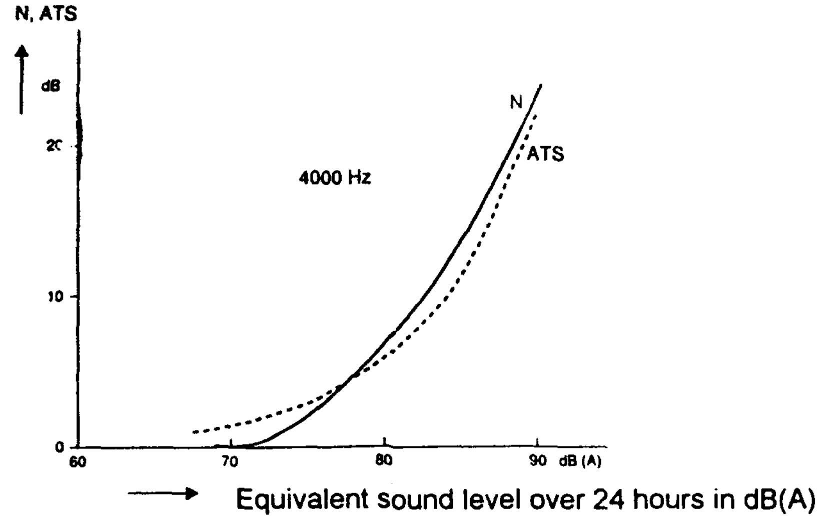

Figure 2. Median value of NIPTS (N0,50) after 40 years of exposure and mean ATS as a function of the equivalent sound level during the 24 hour period. ATS according to Shaw (Shaw, 1983). NIPTS according to ISO 1999 (ISO, 1990), exposure time is equal to 40 years.

Ad a

There appears to be no data to answer the question whether such variations have an effect on permanent threshold shift. Obviously, in occupational noise exposure, exposure to high noise levels during work is succeeded by more quiet hours. These more quiet hours are supposed to be of importance for the recovery from temporary effects on hearing. Apart from exposure to high levels of road traffic noise, in all other cases of non-occupational noise exposure people can also benefit from quiet periods between exposures. Concerning exposure to traffic noise, these exposures are hardly to equivalent sound levels of more than 55 dB(A) during the 24 hour period. If ISO 1999 would be applicable, an equivalent sound level of 70 dB(A) over 24 hours is the onset-level for noise induced hearing loss. Therefore, there seems to be a margin of about 15 dB(A) to cover also the very high exposures to environmental noise with regard to the occurrence of noise-induced hearing loss from such exposures.

In this respect it seems appropriate to look at the outcome of experiments into asymptotic temporary threshold shift (ATS). Many researchers nowadays consider ATS as the maximal value that NIPTS can ever reach (Shaw, 1983). Shaw published a relation between average ATS from exposure to continuous noise and the A-weighted sound level. This relation is for the frequency of 4000 Hz in figure 2 compared with the relation between NIPTS, after an exposure time of 40 years, according to ISO 1999 and taking into account the difference of 5 dB(A) mentioned.

The figure shows that ATS is very small at equivalent sound levels of somewhat over 70 dB(A) and also that there is a remarkable resemblance between ATS and NIPTS.

All in all it seems justified to consider environmental noise, even when it occurs during the total 24 hour period, not able to cause noise-induced hearing loss.

Ad b

Lower background levels between exposures may especially be of importance with regard to impulse noise. Impulse noise at the work place is usually superimposed on high levels of fluctuating background noise and therefore may benefit from the action of the acoustical reflex. This situation seems clearly different in the living environment. And, although it has been shown that impulse noises in occupational situations can be rated according to their equivalent sound levels, this is questionable for impulses in the living environment, such as from fire-crackers, toy guns, other noisy toys and tools. In this respect, the results of a NATO-study group on effects from impulse noise seem to be of use (NATO,1987). They published a number of proposed damage risk contours for exposure

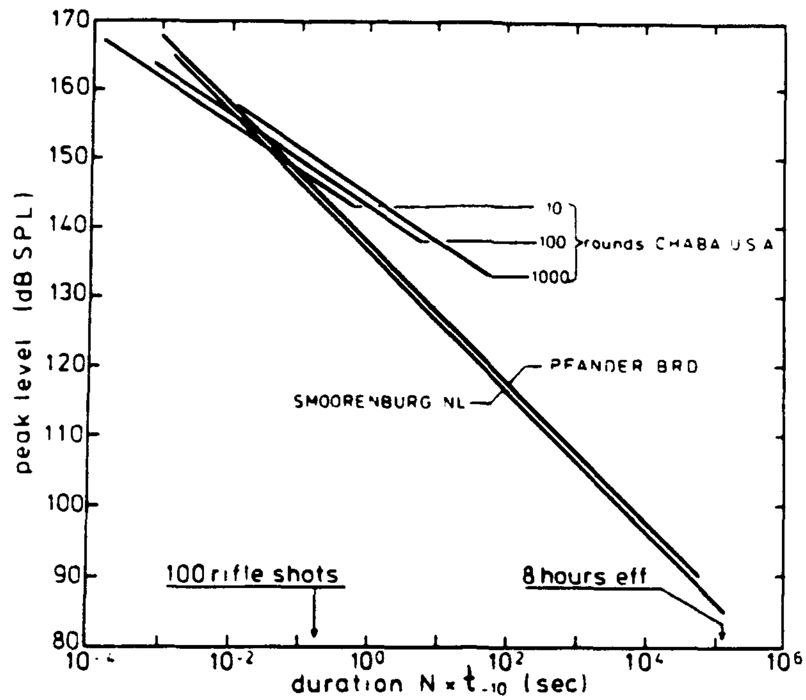

Figure 3. Damage risk contours for impulse noise exposure. On the horizontal axis the total duration of all impulses taken together and on the verical axis the peak sound pressure levels of the impulses.

to impulse noise. These contours are mainly based on research into the effect of shooting noise on hearing, this implies impulses occurring in a very low background noise level. The results are given in figure 3. The contours presented by Smoorenburg (Smoorenburg, 1982) and Pfander (Pfander, 1975 and 1980) support the concept that impulse noise can be rated according to the equivalent sound level. It should be realised, however, that this may be only applicable to exposures with equivalent sound levels over 8 hours of about 85 dB(A). It is likely that this is incorrect for very high exposures to shooting noise. For impulse noise exposure encountered in the living environment, which is considerd not to exceed 85 dB(A), it seems to be correct to rate them according to their equivalent sound level.

Ar .her aspect concerns mechanical damage of the ear. In that respect, peak levels of 140 dB should be considered as potentially hazardous.

Ad c

The study populations used in the determination of the relations given in ISO 1999 all concern adult, mainly male, populations. Non-occupational noise exposures also concern children and elderly people. Although there are indications from experiments with specific types of animals of an increased susceptibility in young specimen, epidemiological studies in children have not been, and should not be, undertaken to demonstrate such an increased susceptibility for noise-induced hearing loss. Also, indications from laboratory studies of an increased susceptibility in people who already have acquired sensori-neural hearing loss, which is probably appropriate for a majority of the elderly, have not been verified by epidemiological research (Passchier-Vermeer, 1993).

Therefore, there seems as yet no epidemiological evidence to consider children and the elderly more susceptible with regard to noise-induced hearing loss than adults.

Ad d

TTS-experiments have shown that exposure to popmusic results in lesser temporary threshold shift than exposure to noise with the same equivalent sound levels. However, this seems to hold only for the first exposures, wheras after five experimental sessions, the beneficial effect of the positive attitude towards the music seems to be absent (Lindgren, 1983).

All in all there do not seem to exist serious objections not to rate non-occupational noise according to the model given in ISO 1999 for occupational noise.

5 Consequences for the occurrence of noise-induced hearing loss in non-occupational noise exposed populations

For far the most of the non-occupational noise exposures, it is completely unknown to which extend people are exposed to the various noise sources and combinations of noise sources. Therefore it is in general not possible to determine the effct of non-occupational noise exposure on the hearing threshold levels of populations. Only for exposure to popmusic, some estimates exist for the situation in the Netherlands. Taking into account the popmusic-habits and the equivalent sound levels during listening, the following characteristic exposure data emerge:

activity	$L_{EX,8h}$	percentage of young people of 15-25 years
popconcert	75-85	5
discotheque	70-85	23
headphones	62-82	50
playing in a popgroup	85-90	10

The data given above are some average outcomes. Clearly, higher and lower noise exposures occur in real life situations. For combinations of activities information is lacking. For all four activities, the total exposure times are all estimated to be at least 5 years. Clearly, playing in a popgroup gives on average the highest exposures. Taking into account that it is estimated that nowadays in the Netherlands half of the young people use headphones, this activity is the second in the list of potentially hazardous popmusic exposures.

There has also been some research into the effects on the hearing of visitors of popconcerts and discotheques. In three studies (Fearn, 1981; Passchier-Vermeer, 1981; Babisch, 1988) the noise-induced hearing losses from these activities showed a remarkable resemblance: all showed these hearing losses at 4000 Hz to be 2 to 3 dB on average. Considering the exposure patterns, these hearing losses are in agreement with the data given in figure 1, taking into account an exposure time of 5 to 10 years.

Several investigators have tried to determine noise-induced effects on hearing from exposure to fire-crackers (Gjaevenes, 1974; Ising, 1988; Gupta, 1989; Brookhouser, 1992). All have shown an increase in the percentage of children with high frequency hearing loss associated with the use of fire-crackers. Ising examined 4000 young people and concluded that 2% of them had an high frequency hearing loss of at least 30 dB due to fire-crackers. Of the 94 children with extensive noise-induced hearing loss, examined by Brookhouser, 9% of them acquired this hearing loss from exposure to fire-cracker noise. Gjaevenes and Gupta compared the hearing threshold levels of more than 600 children before and several times after festivities in which fire-crackers were used and both showed a percentage of the children (1 and 2,5 resp.) to have acquired substantial permanent high frequecy hearing loss from fire-crackers.

Since the noise exposure pattern of children using fire-crackers is unknown, it is impossible to determine whether it is correct to apply the model of ISO 1999 to these exposures.

6 Conclusion

ISO 1999 presents a model for the relationship between occupational noise exposure and noise-induced hearing loss. Above it was shown that the same model can be used to estimate the noise-induced hearing loss from non-occupational exposures. Applying that model the following conclusions can be drawn:

- environmental noise exposure will most likely not lead to noise-induced hearing loss;

- traffic noise exposure while travelling corresponds to, at most, an equivalent sound level over 8 hours of 70 dB(A); this is about 5 dB(A) below the onset-level for noise-induced hearing loss;
- patterns for exposure to indoor sources while at home are unknown; noise-induced hearing loss from such sources is, however, unlikely;
- noise-induced hearing loss may occur from exposure to fire-crackers, shooting and loud noisy toys, such as the toy cap gun; the number of people suffering from such loss is not known as data about the exposure patterns are lacking;
- the main causes of noise-induced hearing loss from popmusic are playing in a popgroup and listening through headphones.

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EFFICACY OF HEARING CONSERVATION PROGRAMS:

PREDICTION OF NIHL; REMEDIATION

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ABSTRACT

The goals of industrial hearing conservation are to prevent hearing loss from noise. The ingredients are noise measurement, noise reduction, avoidance and personal protection. The role of personal dosimetry is stressed and the need for binaural measurements emphasized. The amount of protection provided by personal protectors is less than advertised. The NRR is critiqued.

Audiological screening is the bulwark of monitoring; the techniques are critiqued as is the efficacy of audiometry for early detection of change.

The need for quieter work environments is discussed; it is not enough to protect hearing. The acoustic environment should be friendly. Rehabilitative needs are mentioned.

HEARING CONSERVATION

The goal of a hearing conservation program (HCP) is to prevent hearing loss by monitoring and reducing noise levels or failing this, to separate the worker from the noise either by administrative means or by the use of hearing protective devices (HPD's), to monitor efficacy by means of regular audiometry and to recommend remedial action when necessary. Each of these areas are important components of an HCP, of which health education and periodic program evaluation are also integral parts. Here the discussion will be limited only to occupational hearing loss and its prevention. Stated differently, the goal of an industrial HCP is to maintain hearing of the workers at a level equivalent to the hearing of matched workers with non-occupational noise exposed ears.

Noise measurement is a critical feature of a hearing conservation program both from the standpoint of implementing effective noise reduction and from the point of view of evaluation of pretative occupational hearing loss. Steady state noise has been measured for years and in many industries and trades good data exists for environmental toxin levels i.e. the sound pressure levels at the work site. What does not exist is an adequate data bank of individual noise exposure by workers in different tasks. The early dosimeters merely measured the percentage of time of a work shift that some predetermined level of exposure was exceeded. The introduction of, and improvement in noise dosimeters now permits the accummulation of data about individual daily noise exposure, and allows its expression in a wide range of forms such as L_{ex8}. As measurements are being accummulated, quite significant discrepancies between apparent noise exposure as inferred from work shift length and static noise level measurements and the results of dosimeter measurements made at the workers' ear are sometimes becoming apparent. Furthermore, the ability to place a dosimeter at each ear of a worker has demonstrated some significant difference in exposure of the two ears. This has been a well known phenomenon of rifle shooting with the ear nearest the muzzle being at a greater risk. It is apparent that similar problems exist with heavy equipment use and with a variety of tools. An example from the.construction industry shows a nine decibel difference in sound levels at the two ears when using a heavy electric drill to bore holes into concrete.[1] There is urgent need for more such dosimetry studies for a number of purposes, including more accurate pension evaluation, prediction of at risk workers and identification of the need for the use of HPD's. A worker may have a relatively quiet job for all but half an hour per day, and in the remaining time significantly exceed total daily permissible sound exposure levels with only a twenty minute use of a particularly noisy hand tool or machine and yet be oblivious to the fact that even for such a short period hearing protection is necessary.

The amount of protection provided by hearing protectors is also a critical issue. It is not enough to provide hearing protectors. It is necessary they are effective for the task in hand. In high noise levels such as may be found in the mining industry or with heavy equipment operators where the work place noise may exceed 105 dBA, it is clearly critical that the HPD provide 15 dB or more of protection if the worker is exposed to an eight hour work shift. Conversely, the worker in a typical manufacturing plant may work in noise levels of the low 90's dBA. Here perhaps only six or seven dB of protection are required but before providing HPD's according to category, assurance must be the saught that advertised protection be delivered.

There has been a great deal of controversy about the NRR ratings of HPD's and significant literature exists outlining problems with this technique. Berger[2] has succinctly reviewed these issues. He shows measurements made with a wide range of muffs and plugs indicating the published NRR and the real ear attenuation.

The reason for the discrepancies are both methodological and relate to the way HPD's are worn.

There are few HPD's, plugs or muffs which deliver 10 dB of effective hearing protection to as many as 85% of the work force. Matters are compounded in a work force with a pre-existing hearing loss, for there are persistently claims that the use of HPD's is hazardous because a tolerable unprotected hearing loss is turned into an intolerable severe hearing loss by use of standard protectors. A whole issue related to the introduction of HPD's as a primary means of hearing conservation is raised if there is a significant number of hearing impaired workers in the population being protected. There is evidence that the speech intelligibility of hearing impaired workers is worse when wearing HPD's[2,3] and there is also a concern about safety in their ability to hear unexpected warning noises such as roof talk in a mine. Wilkins[4] has published a thoughtful review about the risks attached to wearing hearing protectors. The recent introduction of level response hearing protectors may improve the situation. Available both as plugs and muffs, they distort sound levels by producing a flat response rather than emphasizing protection in the high frequencies (where NIHL may already exist). To my knowledge no large scale field trial of these devices has been published. New active hearing protectors are being produced which are useful for intermittent noise exposure.[5] They are particularly liked by hunters but also have a place where work site noise is intense but intermittent.

Audiology remains the bulwark of methodology to monitor efficacy of HCP's. The success or failure of a programme is measured by changes in pure tone audiometry although as Robinson[6] pointed out what an HCP is attempting to prevent is hearing handicap something which is not directly measured by audiometry. The direct measures of the handicap, as suggested by, for example, Noble,[7] using questionnaires have proven to be too complex for everyday use and demand an audiological surrogate. These issues are well discussed by King[8] et al. There is considerable remaining controversy about many aspects of industrial audiometry both of methodology and interpretation. Should audiometry be performed manually or by a self recording device? What frequencies should be tested or what intensity steps should the audiometry be performed? Hearing loss produced by noise exposure usually affects the higher frequencies first. Should screening monitoring therefore concentrate on more detailed testing of the higher frequencies or cover the whole spectrum in less detail? There is evidence to suggest that the use of 5 dB steps in monitoring audiometry introduces artifacts of interpretation which 2.5 dB and better yet 1 dB steps eliminate, at the cost of a longer testing time. These matters have been reviewed recently by Simpson[9] et al in relation to proposed American National Standards on the outcomes for characterizing hearing conservation programme effectiveness.

There are more fundamental questions being raised concerning the validity of annual audiometry as a tool to detect changes in hearing threshold in a timely manner, which are well summarized by Hetu[10] who demonstrates that the annual changes in hearing are so small that routine monitoring audiometry is an expensive tool which is theoretically incapable of detecting the minor change of hearing in most ears. Accepting that audiometry is accurately performed, there are issues related

to trigger levels in HCP's. What constitutes a noteworthy shift in hearing for an individual and for a population? Should a standard threshold shift be 10 dB or greater at an average of three frequencies, or is a 10 dB shift at one frequency enough to trigger action or as some jurisdiction place it 25 dB?[11] Where should a base line be placed and when altered? The full components of HCP's are discussed in texts[12] and have been recently well analyzed by Byrne and Mark.[13]

There are still too few publications of the long term results of HCP's. The well known studies by Pell[14] et al demonstrated the efficacy of such programs but most companies have been reluctant to publish their results. Two recent Canadian studies are noteworthy.[15,16] The Workers' Compensation Board of British Columbia is responsible for HCP monitoring in all industry in the province through its Hearing Protection Branch which has monitored and collated audiometric data for hundreds of thousands of workers in a wide range of industries, now for a number of years. They report a significant reduction in worsening of hearing and by inference, benefit from hearing conservation programs largely based upon use of HPD's.

The publication of ISO1999E placed a powerful tool in the hands of auditory researchers. Bertrand[16] and colleagues working in the Quebec mining industry obtained noise exposure measurements in a wide range of jobs. Knowing workers job histories, using ISO1999E, they predicted the expected hearing loss from the very high sound pressure levels found in hard rock mines. The actual hearing thresholds of a group of workers was compared with predicted loss. If they were the same then the program would not be effective. If there was less hearing loss then the program was effective. The presentations related to that work are included in the publication of this conference. They show about 10 dB effective hearing protection in a well established program.

Franks[17] et al in a thoughtful study of a HCP in a large printing company indicated the need for caution in the interpretation of worsening hearing. They point out, in their study group at any rate, that worsening of hearing in the workers employed in a company with an effective HCP was almost certainly due to causes outside the work place such as hunting and shooting and natural aging. There are great national differences in recreational shooting practices: in the USA a hunter may fire a thousand rounds a year in practice and hunting; in Canada recreational use rarely exceeds 20 shells.

The inter-relationship between aging and the toxic effect of hazardous noise has evoked a great deal of interest. It is well reviewed by Robinson.[8] Baughn[18] states that "intense noise produces such high losses so rapidly that the contribution of aging is at first completely lost to view. In a number of years however, the noise induced component decreases and then is lost and the age component which has been steadily progressing at an accelerating rate begins to catch up. Our figures indicate that if the whole population could be kept alive to the age of 86, it would make no

difference (to hearing) what the exposure history of the members of that population had been."

It is suggested that in the first ten years of work in noise the effects of aging and noise exposure are additive and thereafter the combined effect is less than a simple additive one. Most analyses of hearing conservation programmes collectively and individually, do not take adequate note of age.[19] Li[20] has demonstrated in mice that aging and noise are additive only up to a certain level of hearing loss and thereafter there was a blocking interaction.

The prediction of NIHL i.e. identification of the susceptible individual remains an enigmatic goal. Miyakita[21] and colleagues believe that changes in the acoustic reflex threshold are a sensitive predictor of NIHL. This work remains to be confirmed. Recent work by Eric LePage[22] et al suggests that strength of otoacoustic emissions diminishes in individuals whose hearing thresholds are about to be elevated as a result of excessive noise exposure. This affect precedes changes in pure tone hearing threshold and if confirmed, may be an excellent way identifying those at risk. However, a simple test for susceptibility to noise induced hearing loss remains an elusive goal.

The remediation of hearing loss produced by noise exposure is gradually receiving the attention it deserves. The work of Hetu is outstanding. He, in conjunction with his team and together with Noble has looked at many aspects of the noxious effects of noise. In one set of studies they have looked at the acoustic environment in the work place and point out that even if the noise level in the work place is not actually damaging hearing, it still may be acoustically adversarial. Background sound levels may interfere with directional hearing, communication and the detection of warning signals particularly when there are multiple sources in a factory typically there may be nine or ten at one work place. Intensive care units in the hospital have so many monitoring devices that it may be difficult to identify which one requires attention.

The measurement of hearing handicap is a difficult issue. Most hearing conservation programs measure hearing impairment by audiometric means. In recent years, Hetu and his group in Montreal have made significant contributions to the identification, quantification and management of hearing handicap.

They[23] indicate definite anxiety and stress produced by hearing loss in industrial workers and their families, accompanied however with a great deal of denial. A model rehabilitation program has been developed by his group[24] involving both the workers and their spouses. Participation in such programs is unfortunately low.

Even the use of hearing aids is not universally accepted for those with classical high frequency sensorineural hearing loss produced by prolonged exposure to noise, compounded by aging. In our own experience, even today, medical advisors still suggest to workers that nothing can be

done and a hearing aid will not be of benefit. A study performed in our own laboratory[25] suggests otherwise. With hearing loss from occupational causes as with other causes, within limits, the worse the hearing loss the greater the perceived benefit of a hearing aid. With today's devices, good help is provided for those with high frequency hearing loss. Attention should also be paid to other assistive devices such as telephone and television amplifiers.

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INTERPRETING NIHL BY COMPARISON OF NOISE EXPOSED SUBJECTS WITH APPROPRIATE CONTROLS

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Abstract
Hearing Threshold levels (HTL) obtained from a representative population sample were modelled in terms of age and noise immission level, estimated retrospectively by self report. Separate statistical models were developed at each audiometric frequency for males and females in manual and non-manual occupational groups. Analysis of audiograms of 1968 subjects essentially free from conductive impairment or exposure to ototoxic drugs led to a model with parameters of age-squared, average air-bone gap, occupational noise, gunfire noise and occupational-gunfire noise interaction. These models explained up to 62% of the variance in HTL, depending on frequency. In males, estimated occupational noise exposure was associated with increases in HTL mainly at frequencies of 2 kHz and above, although the magnitude of NIHL was lower for a given noise immission level than in other studies. The disparity was attributable to differences in control data, suggesting that other studies may have overestimated NIHL due to lack of sufficiently representative control data. No overall effect of leisure noise or gunfire could be demonstrated in our data.

Introduction

Noise induced hearing loss (NIHL) is viewed conceptually as the difference in hearing threshold level (HTL) between a noise-exposed ear and the same ear not exposed to noise. Both presence and absence of noise exposure cannot occur in the same ear. Hence, the generally adopted definition of NIHL is the difference in HTL between a noise exposed ear and control ears not exposed to noise. Control ears are chosen to be similar in all respects except for noise exposure, usually by choosing noise-free subjects of the same age and sex. However, population studies have indicated that other variables may play an important role in determining HTL, in particular socioeconomic status. Hearing impairment is less prevalent in those in non-manual occupations than in manual occupations, even when noise exposure has been excluded (Davis, 1989). Hence, studies of NIHL involving primarily subjects in manual occupations should draw their controls from noise-free subjects in manual occupations. Otherwise, apparent effects of noise may be due to confounding with occupational group.

We have previously addressed this issue in a statistical modelling study based on a group of 2162

subjects obtained using random sampling techniques in the UK population (Lutman and Spencer, 1991). That study indicated that HTL in noise-exposed subjects, classified according to a restricted set of noise exposure levels, were consistent with other published studies, but that noise-free subjects had substantially poorer hearing than the controls used by the other studies. Hence, the difference between noise-exposed and noise-free subjects (NIHL) was smaller than previously reported. Part of this difference was attributable to occupational group, with males in manual occupations having HTL approximately 4 dB worse than males in non-manual occupations, averaged across the frequencies 0.25 to 8 kHz. A further part may have been due to curtailment of the noise exposure categories.

Any such modelling study has substantial statistical difficulties to overcome. Particular difficulties are encountered when dealing with age, which is inevitably collinear with occupational noise exposure and which exerts a powerful influence on HTL. The distribution of HTL varies with age, and also with occupational group, and is different at each frequency. At 3 kHz and above there are no substantial variations from the normal distribution, but at lower frequencies HTL are more closely approximated by a log-normal distribution. At present, no completely satisfactory statistical method exists to model the data, and the results of any modelling study are subject to some uncertainty. We have partially overcome these difficulties by excluding subjects with HTL near the upper extreme of the distribution and by concentrating on the better-hearing ear, as described below.

In our previous study, we used the General Linear Modelling (GLiM) method (McCullagh and Nelder, 1983) which allows the building of hierarchical linear models. By separating male and female data, we were able to construct satisfactory models to predict HTL from the addition of the main effects of age, occupational group and occupational noise exposure, with no interactions. Separate models of the same form, but with different parameter values, were required for each audiometric frequency. They explained up to 58% of the variance in HTL, depending on frequency. One unsatisfactory aspect of our previous models was an inability to show a significant dependence of HTL on gunfire noise exposure, which we rationalised as due to confounding with age, given that most exposure had been in the World Wars or in military service around that time. However, since publication of that study, we have re-examined that data with a view to achieving a more satisfactory model. The present study describes a refined model and its properties.

Methods

The raw data and its classification have already been described elsewhere (Lutman and Spencer, 1991). Briefly, subjects were drawn from the National Study of Hearing (NSH) conducted by the Medical Research Council's Institute of Hearing Research. The NSH is a large study covering many aspects of hearing in adults of all ages in the UK (Davis, 1989). Subjects had been selected at random from the electoral register. The first stage of simple random sampling identified individuals, who were sent a postal questionnaire. A second non-proportional stratified stage of sampling selected individuals to attend clinics for detailed assessment. Stratification was based mainly on age and reported hearing difficulty. For all analysis presented here, the data were weighted to reflect HTL in the population using the method described by Davis (1989).

The main variables of interest here are the audiometric thresholds obtained by air conduction at 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz, a measure of air-bone gap and estimates of noise exposure, in addition to the demographic variables of age and sex. Methods of measurement have been described in more detail elsewhere (Lutman and Spencer, 1991). Briefly, audiometry was carried out manually according to nationally recognised methods using carefully calibrated audiometers. Estimates of cumulative noise immission were from retrospective reports obtained by structured interview, separately for occupational noise, leisure noise and gunfire. It is recognised that such

estimates can only be approximate, but it will become clear in the following that those uncertainties do not affect our main conclusion. For the present analysis, occupational and leisure noise immission were classified in four bands corresponding to noise immission levels (NIL) of: < 97, 97-107, 107-117 and >117 dB(A). This classification differs from our previous analysis, which aggregated the two higher bands. In fact, leisure noise never exceeded an NIL of 107 dB(A). Gunfire noise was classified in three bands: <1000, 1000-10000 and >10000 rifle rounds, or equivalent for heavier guns. Further details of these classifications are given in our previous report (Lutman and Spencer, 1991).

Subjects over the age of 80 years were excluded owing to difficulties of achieving representativeness in the elderly population. Ears with any conductive hearing impairment (air-bone gap averaged over the frequencies 0.5, 1 and 2 kHz ≥5 dB) were excluded. Any subjects with a history of meningitis, sudden or fluctuating hearing loss or who had received potentially ototoxic drugs were also excluded. Also, subjects with an HTL averaged over 0.5, 1 and 2 kHz in the better ear >80 dB were excluded, on the grounds that this could not arise primarily from noise exposure, and also to improve the statistical modelling, as described above. After these exclusions there remained 1968 subjects with complete audiograms (944 male, 1024 female). Table I indicates the numbers of male and female subjects in each occupational group, for each level of occupational noise exposure.

Table I Numbers of male and female subjects in each occupational group, for each band of occupational noise immission level (NIL).

	Male		Female	
	Non-manual	Manual	Non-manual	Manual
NIL in dB(A)				
< 97	325	278	473	405
97 - 107	49	147	35	84
107 - 117	13	88	4	23
117+	8	36	0	0

Results

Our general approach aimed to differentiate the effects of noise exposure as clearly as possible from other effects, using the GLiM method. In contrast to our previous analysis which used the average of the thresholds of the right and left ears, we concentrated on the ear of each subjects having better average HTL across frequency, on the basis that most noise exposure is symmetrical but extraneous factors might affect one ear more than the other.

Examination of the data showed an unexpected interaction between occupational and gunfire exposure which, although not significant in our previous analysis due to the small numbers of subjects involved, exerted a material influence on the modelling. The interaction demonstrated relatively good hearing in some subjects with high levels of *both* occupational and gunfire noise exposure, possibly due to exaggeration of both types of exposure by a few subjects. A parameter was included to represent this interaction. Leisure noise was found not to be significant and was excluded from the analysis. Examination of the data also revealed that separate models for the two occupational groups could give a better fit than a single model, that age could be modelled more parsimoniously by a quadratic function than by separate parameters for each 10-year age band, and

that even when subjects with an average air-bone gap (abg) greater than 5 dB had been excluded an air-bone gap term improved the model fit slightly.

Table II **Model parameter estimates for males and percentage of variance explained. Numbers in small italics denote values not significantly different from zero (*p*>0.05). NM = non-manual occupation, M = manual occupation.**

		Frequency (kHz)							
		0.25	0.5	1	2	3	4	6	8
NM	C	6.5	1.7	-1.2	-1.7	-2.0	*-0.1*	8.5	*0.1*
	$A\times1000$	1.6	2.2	3.0	4.5	6.6	7.9	8.9	11.1
	B	*0.2*	0.5	0.4	*0.2*	*0.0*	*-0.2*	*0.4*	*0.4*
	N_1	*1.1*	*1.9*	*0.6*	*1.7*	*2.2*	*1.7*	*1.1*	*0.7*
	N_2	*0.0*	*0.0*	*1.6*	*1.3*	10.4	17.5	14.9	*7.8*
	N_3	7.7	9.5	10.2	19.6	29.9	24.1	24.7	16.1
	G_1	-5.1	-4.9	-2.9	*-2.0*	*-0.6*	*-2.8*	*0.3*	*3.9*
	G_2	*-1.0*	*1.3*	*2.9*	*-0.5*	*-0.6*	*-4.4*	*-3.6*	*1.2*
	NG	*13.3*	*12.6*	16.5	*0.6*	*-8.9*	*-3.1*	*1.7*	*9.1*
Var. (%)		15.2	24.9	41.2	45.1	55.0	55.5	55.0	61.7
M	C	6.5	2.6	*0.9*	*-0.3*	*1.8*	2.8	9.5	*1.7*
	$A\times1000$	2.6	2.7	3.0	5.3	7.9	9.6	11.0	12.5
	B	0.3	*0.3*	*0.3*	*0.5*	0.8	0.7	0.8	*0.5*
	N_1	*0.2*	*0.6*	*1.1*	*1.0*	*1.6*	*1.6*	*0.2*	*-1.4*
	N_2	2.9	4.3	3.9	5.4	8.7	10.1	5.0	*2.4*
	N_3	2.7	4.2	7.4	12.2	16.4	20.0	13.3	10.0
	G_1	*-2.0*	*-1.5*	-2.6	*-0.8*	*-0.6*	*3.3*	*1.9*	*3.8*
	G_2	*0.8*	*-2.4*	*-3.3*	*-3.0*	*-0.5*	*5.7*	*-0.2*	*2.6*
	NG	*-0.8*	*-1.3*	*-4.0*	*-7.3*	*-13.9*	-21.7	*-10.6*	*-12.8*
Var. (%)		23.5	23.5	28.2	36.9	46.9	55.0	54.1	61.6

Hence, based on many trials of different statistical models, our final model took the following form for each sex and occupational group.

$$HTL_i = C_i + A_i \times age + B_i \times abg + N_{ij} + G_{ik} + NG_{ijk} + e_{ijkl}$$

where HTL_i is the HTL in the better ear at the frequency given by the index i (i = 0,1,...7), C_i, A_i, B_i are constants for each frequency i, *age* is the subject age in years, *abg* is the maximum air-bone gap over the frequencies 0.5,1 and 2 kHz, N_{ij} is a parameter corresponding to the frequency i and the occupational noise exposure band j (j = 0, 1, 2 or 3), G_{ik} is a parameter corresponding to the frequency i and the gunfire noise exposure band k (k = 0, 1 or 2), NG_{ijk} is a parameter

corresponding to the frequency i and the conjunction of values of j and k of 2 or greater, and e_{ijkl} is an error term assumed to be normally distributed with zero mean. We have examined many different methods to model the error term and found that our conclusions are similar for all reasonable models. Hence, the exact nature of the error term is not critical and our chosen model would appear to be robust.

Table III Model parameter estimates for females and percentages of variance explained. Numbers in small italics denote values not significantly different from zero (p>0.05). NM = non-manual occupation, M = manual occupation.

		Frequency (kHz)							
		0.25	0.5	1	2	3	4	6	8
NM	C	4.8	*0.8*	*-0.1*	*-0.9*	*-0.5*	*-0.5*	7.2	*0.2*
	A×1000	2.7	3.0	3.3	4.4	5.4	6.4	8.1	9.7
	B	*0.2*	0.5	0.6	0.7	0.5	0.7	0.7	0.7
	N_1	*1.6*	*1.4*	*0.4*	*-0.9*	*0.5*	*-0.8*	*-0.5*	*-1.8*
	N_2	*-0.4*	*-1.4*	*3.7*	*6.6*	*2.4*	*-4.0*	*5.5*	*-2.1*
Var. (%)		25.9	28.8	30.9	39.9	44.2	49.4	48.1	52.7
M	C	7.0	3.4	2.6	*0.5*	*1.2*	*1.4*	9.7	*0.6*
	A×1000	2.5	3.0	2.8	4.2	5.1	6.2	7.9	10.0
	B	*0.2*	0.5	*0.1*	*0.1*	*-0.1*	*0.0*	*0.3*	*0.4*
	N_1	*-0.8*	*-0.6*	*0.0*	*0.7*	*1.3*	*1.6*	*0.3*	*-2.8*
	N_2	*2.4*	4.0	4.4	5.0	*4.0*	*5.5*	*3.7*	*5.6*
Var. (%)		18.0	22.2	20.4	33.6	36.1	43.2	45.7	55.0

The set of models can be summarized for each sex and occupational group by constants C, A and B, and the parameters N, G and NG, having 4, 3 and 2 values respectively. The constant C effectively incorporates the baseline values of the other parameters (having zero index) leaving redundant zeros for the lowest levels of N, G and NG. There were only three female subjects with any material gunfire noise exposure. Hence, for simplicity, the G and NG parameters were excluded from the female model. Also, no females had high levels of occupational noise and therefore parameter N had only three levels (N_0, N_1 and N_2). Table II gives estimates for males of constants C, A and B, and for parameters N, G and NG, for each audiometric frequency. Separate sets of estimates are given for manual and non-manual occupations, with estimates of the variances accounted for by each model. Table III gives similar data for females.

Examination of Table II shows significant effects of the highest noise exposure band (N_3: NIL >117) at all frequencies in both occupational groups, with a maximum of 29.9 dB in the non-manual group at 3 kHz and 20.0 dB in the manual group at 4 kHz. Lesser effects are evident at the immediately lower level (N_2: NIL 107-117). There are no significant effects at the lowest noise-exposed level (N_1: NIL 97-107) at any frequency. This latter level might be accrued by working for 50 years at daily levels between 80 and 90 dB(A), or correspondingly shorter durations at higher levels. Note that this is a mean effect across all exposed subjects and does not deny that some more susceptible individuals will sustain greater damage. Gunfire noise did not demonstrate

any meaningful pattern of significant effects. Note that apparently sizeable effects in the Table may not be statistically significant due to restricted subject numbers for a particular level of the parameter.

Limited support for the contention that male and female subjects are similarly affected by noise is given by comparison of Tables II and III. However, shortage of noise-exposed females, especially in the non-manual group (see Table I), prevents us comparing males and females in more detail in the present analysis.

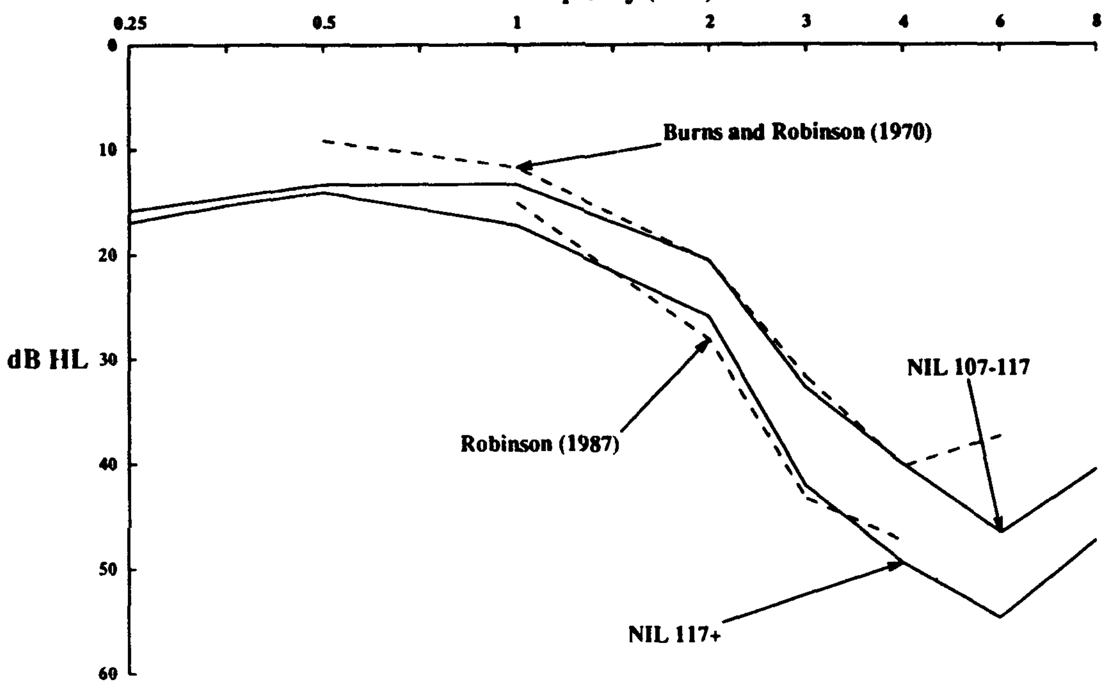

Figure 1. HTL estimated from the present study for male subjects aged 55 years in manual occupations, with NIL of 107-117 and 117+ dB(A), compared with Burns and Robinson (1970) and Robinson (1987), both for male subjects aged 55 years with an NIL of 110 dB(A).

Taken at face value, the effects of noise in males appear to be smaller than reported elsewhere. For example Burns and Robinson (1970) modelled their data in a form that predicts a median NIHL at 4 kHz of 25.7 dB for a NIL of 110, and 42.3 dB for a NIL of 120 dB(A). These NIL values have been chosen to be close to the mean values of subjects with occupational noise parameters N_2 and N_3 for which our NIHL estimates are 14 and 22 dB respectively, averaged across occupational groups. Comparison with the NIHL model of Robinson (1987) leads to a similar conclusion. Measures of NIHL require assumptions about controls as described above. It is safer to compare unadjusted HTL in noise-exposed subjects across studies rather than the *differences* used to deduce NIHL. Figure 1 compares HTL from our model with those of Burns and Robinson (1970) and Robinson (1987), using subjects exposed to a NIL of 110 dB as an example[1]. Our parameter values for males in manual occupations are chosen as these correspond most closely to the mix of subjects in the other studies. An age of 55 years has been chosen as this would allow the NIL of 110 dB(A)

[1] The estimated HTL at each frequency is obtained by adding C, $A \times age^2$ and N, choosing the appropriate values from Table II.

to be reached realistically due to exposure for 35 years to a daily level of 95 dB(A) for 8 hours per day. The level of 95 dB(A) and duration of 35 years were used in the Robinson model which does not depend on NIL. The figure also shows the prediction from our model for the N_3 group, for comparison.

Examination of Fig. 1 shows remarkably good agreement between our model and that of Burns and Robinson. At frequencies between 2 and 4 kHz the agreement is virtually exact. Hence, our subjects show similar HTL to comparable subjects in the Burns and Robinson study. In fact, if account is taken of our selection of better-ear data rather than the average of right and left ears, our subjects would appear to have poorer hearing. Our N_2 data are somewhat better than the Robinson model would predict (coincidentally our N_3 data correspond almost exactly). Part of this difference is attributable to our choice of better-ear data, and a further part to the lack of screening for conductive hearing loss in some of the data sources used by Robinson. Taking these comparisons together, and other comparisons not reported here, our noise-exposed data show similar HTL to comparable studies when unadjusted HTL are compared. Hence our refined model continues to show that the marked difference in apparent NIHL is due to differences in *control* data.

Discussion

By refinement of our model structure, we have been able to improve the description of the male data set, compared with our previous report (Lutman and Spencer, 1991). The refined female model did not lead to an increase in variance explained although it is more parsimonious in the number of parameters. Crucially, we have increased the variance explained in the male model at 4 kHz where the greatest leverage on NIHL is achieved (from 52 to 55%).

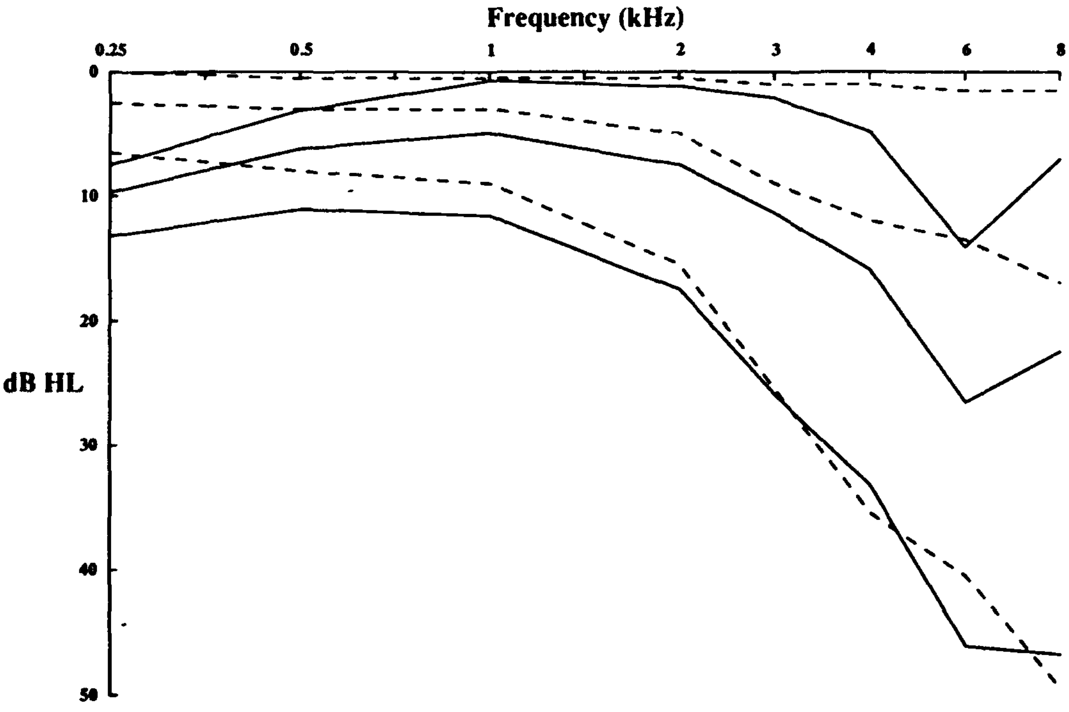

Figure 2. HTL estimated from the present study (solid curves) for noise-free males in non-manual occupations at ages (from top to bottom) of 25, 45 and 65 years. Equivalent data from ISO 7029 shown by dashed curves.

The main strength of our data set is its rigorous sampling, and hence evident representativeness, and the fact that noise-exposed and noise-free subjects were sampled and tested identically. This minimizes control bias. The main weakness is the lack of measured noise levels. Any estimate based on self-report, albeit using a carefully structured protocol, must accrue substantial uncertainty. Lack of accuracy in noise level estimation could blur the distinction between noise-exposed and noise-free subjects, thereby diluting any apparent effect of noise. Therefore, we sought to examine the possibility that our modest effects of noise may have been attenuated due to lack of measured noise levels. Firstly we compared HTL in our noise-exposed subjects with those reported by other studies that permit comparison, as described above, and found no evidence that our noise-exposed group is diluted materially with relatively noise-free subjects. The remaining possibility is that our nominally noise-free group was contaminated by noise-exposed subjects. There is no reason to suspect that denial of noise exposure in our study was any different from denial of noise exposure in the other studies, or their sources of control data. Furthermore, our criterion determining the noise-free category (N_0) did not influence the results materially. In Table II it can be seen that even subjects in noise-exposed category N_1 did not have significant NIHL. Further, we have applied successively stricter criteria to define the noise-free group and have not observed any improvement in HTL. Thus, our noise-free data, which are based on substantial subject numbers, appear to be robust.

The conclusion is that HTL measured in a representative sample of the population of screened noise-free subjects are substantially poorer than the controls used by other studies. One of the studies used for comparison (Robinson, 1987) is a compendium of all major published data available at the time of writing. A similar conclusion is reached by comparing our data with ISO 7029 (1984). Figure 2 illustrates such a comparison, taking our data for noise-free males in non-manual occupations as an example. Ages of 25, 45 and 65 years are shown for illustrative purposes. This comparison shows a substantial disagreement, with median HTL given by ISO 7029 more acute than even our better-ear data for the non-manual group. The disparity is greatest for the younger ages and disappears in this comparison at frequencies of 2 kHz and above by the age of 65 years.

Conclusions

Examination of population hearing threshold levels according to age, sex, occupational group and noise exposure, having screened for conductive hearing loss and other risk factors, suggests that previous studies may have overestimated NIHL due to insufficient control of noise-free subjects. ISO 7029 does not appear to be suitable as a general source of control data for such purposes. There is a need for an improved source of control data for use in studies of NIHL and also for studies of the effects of other surdogens.

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ACTUAL EFFECTIVENESS OF HEARING PROTECTION IN HIGH LEVEL IMPULSE NOISE

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ABSTRACT

Current exposure limits for high intensity impulse noise contain factors for hearing protection which are based on very limited data. Recent studies in the U.S. and in France have provided new insights into the protection afforded by hearing protective devices. For impulses with an A-duration of approximately 3.0 ms, protection was found to be adequate for peak pressures up to 190 dB SPL for 6 impulses and 187 dB for 100 impulses. Protection was found to be adequate for 6 impulses with an A-duration of approximately 0.8 ms up to 196 dB SPL. For this A-duration, protection was adequate for 12 impulses up to 190 dB SPL and for 50 and 100 impulses at 187 dB SPL. The hearing protectors used in these studies were earmuffs with perforations in the cushions which provided essentially no attenuation below 500 Hz. In a series of French studies, hearing protection was found to be adequate for impulses produced by a variety of weapons with peak pressures ranging from 165 dB SPL to 180 dB SPL. These included small arms with A-durations less than 1.0 ms, artillery with A-durations of approximately 3.0 ms, and other weapons with durations between these extremes. A variety of insert hearing protectors (earplugs) was used in these studies. All had perforations which resulted in poor low frequency attenuation. In both sets of studies, conventional attenuation rating schemes greatly underestimated the actual protection afforded by the hearing protective devices. Direct measurements of the pressures under the earmuff showed these peak levels can be as high as 182 dB SPL without significant effects on hearing.

Efficacité Réelle des Protecteurs Auditifs Pour des Expositions à des Bruits Impulsionnels de Niveau de Crête élevé

RÉSUME

Les critères d'exposition usuels aux bruits impulsionnels de fort niveau permettent de tenir compte de la protection auditive utilisée mais seulement à partir de résultats très limités. Des études récentes réalisées aux Etats-Unis et en France ont apporté de nouvelles indications quant à la protection effective fournie par les protecteurs auditifs. Pour des impulsions d'une durée de première phase positive (durée A) d'environ 3 ms, la protection employée était adéquate pour des niveaux de surpression de crête allant jusqu'à 190 dB SPL pour 6 coups et jusqu'à 187 dB SPL pour 100 coups. La protection était également adéquate pour 6 coups d'ume durée A d'environ 0,8 ms et de 196 SPL de surpression de crête. Pour la même durée, la protection était adéquate pour 12 coups jusqu'à 190 dB SPL et pour 50 et 100 coups jusqu'à 187 dB SPL. Les protecteurs auditifs utilisés dans ces études étaient des serre-tête dont les coussinets avaient été perforés et qui, de ce fait, n'apportaient pas d'atténuation pour les fréquences inférieures à 500 Hz. Dans une série d'études réalisées en France, la protection auditive était adéquate pour des expositions à des bruits impulsionnels produits par des armes et dont les surpressions de crête allaient de 165 à 180 dB SPL. Ces bruits correspondaient soit à ceux produits par des armes légères (durée A inférieure à 0,1 ms), soit à ceux produits par des pièces d'artillerie (durée A d'environ 3 ms), ainsi qu'à ceux d'autres armes de durées A intermédiaires. Dans ces études, les protecteurs auditifs utilisés étaient des bouchons d'oreilles de différents types qui comportaient tous des perforations induisant une faible atténuation aux basses fréquences. Dans ces deux types d'études, l'atténuation des protecteurs auditifs mesurée de facon conventionnelle sous-estimait la protection effective apportée par les protecteurs. Des mesures directes de pression réalisees sous la coquille des serre-tête ont montré que les niveaux de crête pouvaient atteindre 182 dB SPL sans que l'on observe d'effet significatif sur l'audition des sujets.

Introduction: In 1968, CHABA published a "Proposed damage risk criterion for impulse noise (gunfire)" derived from Coles et al. (1968). This criterion was based on data from exposure of unprotected humans and made no provision for extending the limit when hearing protection is used. Three basic approaches have been used to resolve this shortcoming. The first was to estimate the protection and simply raise the unprotected exposure limit by the amount of the protection. The second approach was to expose people with protection to an impulse noise and look for effects on their hearing. Finally, the impulse noise penetrating the protector can be measured and the unprotected limits applied to this measured pressure-time signature.

Fixed protective values: The development of the military standard, which establishes the exposure limits for military equipment in the United States, is an example of the first approach. Based on the results of a study of exposure to shoulder-fired antiarmor weapon noise with earplugs, Garinther and Hodge (1971) concluded that hearing protectors provided 29 dB of protection. This amount of protection was incorporated into MIL-STD-1474 to establish our current exposure limits by raising the CHABA (1968) criterion by this amount (Garinther and Hodge, 1981). Thus, twenty-nine dB of protection is accorded to any protector regardless of its attenuation characteristic. In Germany, Pfander (1975) developed an impulse noise exposure limit using 25 dB as the amount of protection. The protected limit is simply the unprotected limit raised by 25 dB.

Direct determination studies: In the 1970s, the impulse noise produced by new heavy weapons became a matter of concern to the U.S. Army because it exceeded the protected exposure limits. This led to studies designed to determine whether then current hearing protection was adequate for these weapons. Patterson et al., (1985) showed that foam earplugs provided adequate protection for artillery noise which exceeded the limit. Patterson and Mozo (1987) showed that the same protection was adequate for the noise of a shoulder-fired antiarmor weapon which also exceeded the protected limit. These results are clearly contradictory to our current exposure limits. One possible explanation is that the 29 dB protection factor is not correct for all hearing protectors. It is known that the foam earplugs provide large amounts of attenuation when they are properly used as they were in these studies. Unfortunately, direct estimates of the amount of protection cannot be derived from these results. While these studies showed that the earplugs used provided adequate protection, they did not establish an upper bound on the noise levels for which they are adequate.

In order to establish upper bounds for exposure to the high intensity impulse noise typical of most heavy weapons, a series of studies was undertaken in the United States. These studies used a common approach with only the exposure impulse changing between studies. Both the level and the number of impulses were varied. Volunteers were given a series of exposures starting with six impulses at a level below current exposure limits. On successive exposure days, the level was raised while the number of impulses remained fixed at six. This process was repeated until a significant threshold shift (over 25 dB at any frequency) was observed or until the threshold of nonauditory injury (Dodd et al., 1990) was reached. Then the number of impulses was increased and exposures continued at a reduced level. The numbers of impulses used were 6, 12, 25, 50, and 100. The goal was to find the lowest level for each number of impulses which resulted in a significant threshold shift (TS). Approximately 60 volunteers, military personnel with less than 5 years of service, participated in each study.

Table 1. Average peak pressures and durations for the impulses at 5 meters from the source.

Intensity code	Peak (kPa)	Peak (dB)	A-duration (ms)	B-duration (ms)	C-duration (ms)	D-duration (ms)
1	10	174	2.3	15.6	1.7	6.0
2	14	177	2.5	17.4	2.0	7.8
3	19	180	2.6	17.2	2.1	7.8
4	26	182	2.9	18.0	2.3	7.6
5	36	185	2.8	18.9	2.6	8.2
6	49	188	2.9	20.0	2.8	9.9
7	69	191	3.0	21.2	2.8	8.3

The first of these (Patterson and Johnson, 1990) used impulses typical of artillery weapons. These impulses were produced by detonation of explosive material 5 meters from the location of the volunteers and approximately 3 meters above the ground. Figure 1a shows a typical pressure-time signature for this impulse. Table 1 shows the average levels and durations for the series of intensities.

The study design initially included three levels of hearing protection. The plan was to find the limit of the poorest protector first; then to find the limit for improved protection; and finally, to find the limit for the maximum protection. The first hearing protector used was an earmuff compatible with the U.S. Army infantry helmet. The second and third levels were the foam earplugs and the foam earplugs combined with the earmuff; however, these were never used for reasons which will become obvious. Figure 2 shows the attenuation of the earmuff.

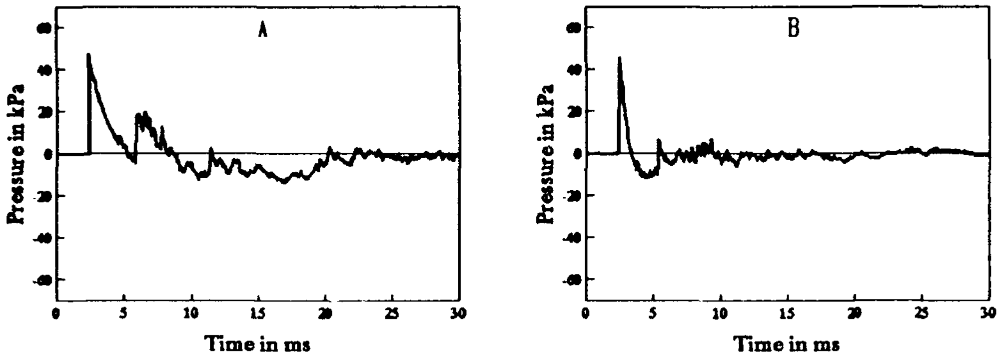

Figure 1. Pressure-time signatures: 5 meters (panel A) and 1 meter (panel B) from source

The first group of volunteers started the study using the earmuff. Forty-nine of these were exposed to 6 impulses at 190 dB SPL and 39 also were exposed up to the 100 impulses at 187 dB SPL. None showed any significant TS. This led to a change in the study design. The hearing protection became the same earmuff modified by introducing intentional leaks in the ear seals. The attenuation at octave frequencies fcr the modified earmuff also is shown in Figure 2. Notice the low frequency attenuation has been eliminated and the high frequency attenuation reduced. This attenuation is typical of what might be found with a poor fit of the standard earmuff in which the seal is compromised. Another group of 60 volunteers was exposed wearing the modified earmuff. This time 56 volunteers progressed to the exposure to 6 impulses at 190 dB SPL with only one showing a significant TS; 58 were exposed up to 100 impulses at 187 dB SPL with only 2 showing a significant TS. These results were interpreted to indicate that the modified earmuffs provide adequate protection for all exposure conditions used in this study.

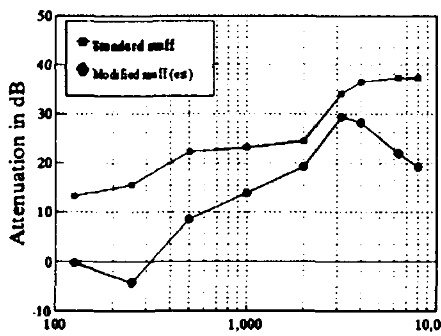

Figure 2. Average attenuation for standard and modified earmuffs

For the next study (Patterson and Johnson, 1993), the exposure stimuli were produced by detonating explosive material inside a 60 cm diameter steel tube. The volunteers were located so their heads were approximately 1 meter from the open end of the tube. The pressure-time signature for this impulse is shown in Figure 1b. Table 2 contains the levels and durations for the intensity levels used in this study. The first level hearing protection was the modified earmuffs described earlier. All other procedures remained the same.

Sixty-five volunteers started the study and 59 progressed to the exposure to 6 impulses at 196 dB SPL. Of these, four showed significant TS at the highest level. Statistically the hypothesis that 95 percent of the exposed population is protected adequately can be rejected when 6 or more volunteers show a significant TS. Therefore, the modified earmuffs provide adequate protection for 6 impulses at 196 dB. For exposure to 12 impulses at 193 db SPL, 6 of the 61 volunteers showed a significant TS. The protection is considered inadequate for this condition as well as the 193 dB level for more than 12 impulses. At 190 dB SPL, only 4 of 59 volunteers showed a significant TS after exposure to 25 impulses; while at 50 impulses resulted in 7 out of 55 volunteers with a significant TS. At this level, the protection becomes inadequate between 25 and 50

Table 2. Average peak pressures and durations for the impulses at 1 meter from the source.

Intensity code	Peak (kPa)	Peak (dB)	A-duration (ms)	B-duration (ms)	C-duration (ms)	D-duration (ms)
1	16	178	1.1	10.8	1.2	2.5
2	23	181	1.0	12.1	1.0	2.2
3	34	185	0.9	9.5	0.7	1.9
4	48	188	0.9	10.8	0.6	1.3
5	66	190	0.8	15.4	0.6	0.8
6	94	193	0.8	53.8	0.5	0.7
7	130	196	0.8	65.0	1.0	1.2

impulses. At 188 dB SPL, the modified earmuff provided adequate protection for all numbers of impulses; 50 impulses produced significant TS in only 3 of 51 volunteers and 100 impulses at this level resulted in significant TS in only 3 of 44 volunteers. These results are summarized in Table 3. The protection provided by the unmodified earmuff was considered adequate for all exposure conditions included in this study.

Table 3. Summary of conditions for which the modified earmuffs provide adequate protection for combinations of level and number of impulses.

	Number of impulses				
Level	6	12	25	50	100
196	A	NA	NA	NA	NA
193	A	U	U	U	U
190	A	A	A	U	U
188	A	A	A	A	A

A=adequate, U=inadequate, NA=exceeds nonauditory limit

While these studies were being conducted in the U.S., French researchers were conducting a complementary set of studies (Dancer et al., 1992). The U.S. studies focused on large numbers of volunteers exposed under the same conditions for statistical reliability and included only two hearing protector conditions, both earmuffs. In contrast, the French studies used more different hearing protectors, all earplugs, with a smaller number of volunteers for each exposure condition. They also focused on protectors with little or no low frequency attenuation in an effort to maintain face-to-face voice communication. The U.S. studies used explosives to achieve exposure levels exceeding those produced by existing weapons; the French studies used a variety of weapons.

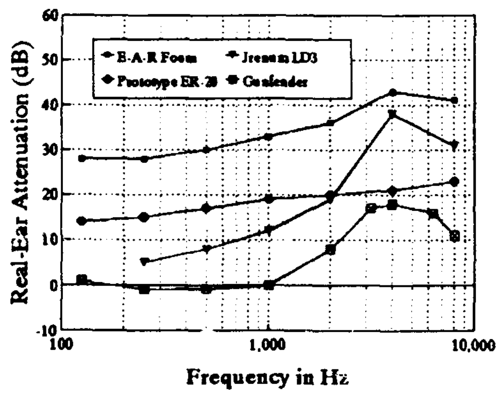

Figure 3. Attenuation of the protectors in the first experiment

Figure 3 shows the attenuation of the hearing protectors used in the first French experiment. Note that the foam plug is the same as that used by Patterson et al. (1985) and Patterson and Mozo (1987). The other protectors are designed to have low attenuation compared to the foam plug. In this experiment, between 6 and 20 volunteers were exposed to the firing of the howitzer for 10 to 20 rounds. The peak levels were between 175 and 176 dB SPL. No TS exceeding 15 dB was observed after these exposures. These results for the foam earplug are not surprising in view of the findings of Patterson et al. (1985); however, the results for the Gunfender are surprising since it has no attenuation up to 1.0 kHz. This may be a result of its reported growth of attenuation with level (Forrest and Coles, 1969).

In the second experiment, Dancer et al. (1992) used five different hearing protectors. Figure 4 shows the attenuation of these protectors. Three to 5 volunteers were exposed to the rifle fired in a reverberant space (peak levels of 150 to 161 dB SPL), an antitank weapon (peak levels of 182 to 183 dB SPL at the right ear and 178 to 181 dB SPL at the left ear), and to the howitzer (peak levels of 175 to 176 dB SPL). None of the volunteers showed a TS which exceeded the 25 dB criterion used in the U.S. studies to define unacceptable TS. There is no evidence that any of the protectors used in these experiments fail to provide adequate protection. These studies indicate that a variety of protectors with little attenuation at the low frequencies can provide adequate protection for high intensity weapons noise.

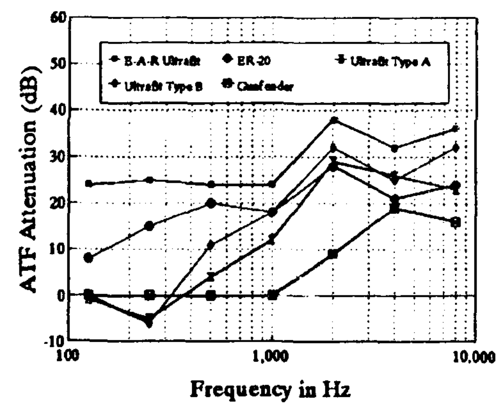

Figure 4. Attenuation of the protectors in the second experiment

Levels under hearing protection: The third approach to estimating the effectiveness of hearing protectors for high intensity impulse noise is to measure the pressure-time signature under the protector and compare the measured parameters to the unprotected exposure limit. This approach

differs from the approach of raising the unprotected limit by a protection value in that it is based on the specific protector and the specific impulse. Recently, Pekkarinian et al. (1992) applied this method to heavy weapons noise and concluded that the levels under the earmuffs exceeded the unprotected limits from both CHABA and Pfander. Johnson and Patterson (1992) also have reported that the levels under the earmuffs of the volunteers participating in the studies described above greatly exceed the unprotected limits. However, in this case the lack of any effect on hearing was documented. This indicates that levels measured under hearing protectors should not be compared to unprotected limits to estimate the effectiveness of the hearing protection.

Summary: There is no generally accepted method for calculating the protection against high intensity impulse noise afforded by hearing protectors. Of the three possible approaches, the use of fixed protection values independent of the hearing protector, have been shown to underestimate the actual effectiveness of hearing protectors. Studies designed to determine the actual effectiveness of hearing protectors are the best, but most costly approach. These studies have shown that protection is adequate for levels which exceed our current exposure limits. Further, these studies clearly demonstrate that the hazard of impulse noise cannot be evaluated by measuring under the hearing protector and using unprotected exposure criteria. This approach generally will lead to a gross underestimate of the actual effectiveness of the hearing protector.

ACKNOWLEDGEMENT

The authors thank Dr. A. Dancer for his French translation of the abstract for this paper.

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PREDICTIONS OF NIHL BASED ON ANIMAL STUDIES: SPECIES DIFFERENCES AND THEIR IMPLICATION

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Abstract

Many studies have shown that the physiologic and anatomic consequences of identical acoustic overstimulation can be very different from one species to another. It is generally difficult to determine the origin of these differences in susceptibility to noise because the experimental conditions are very different from one experiment to another and from one species to another.

We hypothesized that the cochlear structures exhibit the same mechanical resistance to acoustic stress independently of the animal species considered. In that case, the differences observed in the auditory sensitivity of various animal species would essentially originate from the conditions under which the acoustic stimuli are transmitted from the free field to the inner ear. We measured the threshold shifts and the histological alterations induced by the same acoustic stimuli (pure tones of 2 - 4 and 8 kHz at levels ranging from 80 to 132 dB SPL and applied during 20 minutes) in the cat, the chinchilla, and the guinea pig. The interspecies differences in noise susceptibility were compared to the transmission characteristics of the peripheral mechanical system (external and middle ear) assessed by intracochlear acoustic pressure measurements.

The transmission of the acoustic stimulus from the free field to the inner ear seems to be responsible for the largest part of the interspecies differences in auditory susceptibility. This observation is very important if one searchs for the possibility to extrapolate, from a quantitative point of view, NIHL measurements performed on the animals to humans and to improve the usefulness of the animal models.

Résumé

De nombreuses études ont montré que les conséquences physiologiques et anatomiques d'une surstimulation acoustique pouvaient être très différentes d'une espèce animale à l'autre. Il est généralement difficile de déterminer l'origine de ces différences car les conditions expérimentales sont très diverses d'une étude et/ou d'une espèce à une autre.

Nous avons fait l'hypothèse selon laquelle les structures cochléaires auraient la même résistance mécanique au bruit quelle que soit l'espèce considérée. Dans ce cas, les différences interspécifiques de susceptibilité au bruit seraient essentiellement dues aux conditions de transmission du signal acoustique depuis le champ libre jusqu'à l'oreille interne. Nous avons étudié chez le chat, le chinchilla et le cobaye, les déficits auditifs et les lésions histologiques produits par l'exposition à des sons purs (2, 4 et 8 kHz) de niveau compris entre 80 et 132 dB SPL présentés pendant 20 minutes. Les différences interspécifiques observées ont été mises en relation avec les caractéristiques de la fonction de transfert de "l'appareil mécanique périphérique" (oreille externe et oreille moyenne) de chacune des espèces étudiées. Cette fonction de transfert a été déterminée au moyen de la mesure de la pression acoustique intracochléaire.

Les différences interspécifiques de susceptibilité aux bruits semblent principalement dues à la façon dont le signal acoustique est transmis du milieu extérieur à l'oreille interne, c'est-à-dire à la fonction de transfert de l'oreille externe et de l'oreille moyenne de chaque espèce. Cette constatation est importante lorsqu'on cherche à extrapoler, de l'animal à l'homme et sur le plan quantitatif, les mesures des déficits auditifs entraînés par les bruits. Elle offre de nouvelles possibilités pour une meilleure utilisation des modèles animaux dans le but de protéger l'homme contre les nuisances sonores.

Introduction

In man, only temporary and totally reversible modifications of the auditory function can be induced for experimental purposes. Therefore, it is necessary to use animal models to study most of the problems related to the effects of noise on hearing: i.e., the relations existing between the Temporary Threshold Shifts (TTS), the Permanent Threshold Shifts (PTS) and the lesions of the Corti's organ, the relations between Noise-Induced Hearing Loss (NIHL) and aging, the interactions between noise and other agents, the efficiency of preventive and/or curative treatments of the acoustic trauma.... The most widely used species for these investigations are the cat, the chinchilla, the gerbil, the guinea pig and the squirrel monkey. Yet the physiologic and anatomic consequences of identical overstimulation can be very different from one species to another and "there is the general view that some species are intrinsically more or less susceptible to noise exposure than others" (Saunders and Tilney, 1982). Actually, it is generally difficult to determine the origin of the differences in susceptibility to noise because the experimental conditions are not the same from one experiment to another and from one species to another. Anyhow, these differences do not allow to extrapolate quantitatively the results obtained in animals to man: the use of animal models is presently unsuitable for determining the maximum permissible continuous or impulse noise exposure for humans (either peak level or noise dose).

Is there any possibility to use the results obtained from animals to test the validity of the current exposure criterions, to improve these criterions and/or to propose new ones (Dancer, 1981)?

NIHL animal experiments

For a long time, many experiments related to the effects of noise on hearing have been performed on various animal species (for an early review see Trahiotis, 1976). However, it is almost impossible to identify in the literature a situation in which: (i) the acoustic stimulus (amplitude, spectrum, duration), (ii) the exposure conditions (free field or closed circuit), (iii) the techniques and the time at which they are used after the exposure to test for hearing loss (behavioral audiometry, evoked potentials or electrocochleography) and to assess the morphological damages (optical or scanning electron microscopy), are identical in two different species.

Nevertheless, some indications can be obtained from a few closely related experiments:

- Dolan et al. (1975) exposed cats during 1 hour to pure tones of 1 - 2 and 4 kHz at levels ranging from 113 to 133 dB SPL (these levels have been corrected to correspond to the free-field exposure conditions),
- Hunter-Duvar and Bredberg (1974) exposed chinchillas during 12 minutes to a 1 kHz pure tone at 120 dB SPL (corrected free-field exposure),
- Poche et al. (1969) and Erlandsson et al. (1980) exposed guinea pigs during 4 and 6 hours to pure tones of 1.3 - 2 and 3.8 kHz at levels ranging from 102 to 150 dB SPL,
- Hunter-Duvar and Elliott (1972, 1973) exposed squirrel monkeys during 2 to 12 hours to pure tones of 1 and 2 kHz at 120 and 140 dB SPL.

The results obtained by these authors indicate (i) that a 1 kHz pure tone at 120 dB SPL presented for 12 minutes to the chinchilla induces more Threshold Shift (TS) than the same stimulus presented for 12 hours to the squirrel monkey, (ii) that a 1- 1.3 kHz pure tone at 120 dB SPL presented for 12 minutes to the chinchilla produces as much morphological damage as the same stimulus presented during 6 hours to the guinea pig, (iii) that after 1 hour exposure to pure tones of 1 - 2 or 4 kHz at 120 or 125 dB SPL, hearing damage is larger in the cat than in the squirrel monkey or in the guinea pig. In a TTS study Mills et al. (1970) also noticed that the chinchilla is more sensitive than man by about 10 dB when exposed to an one-octave band stimulus centered on 0.5 kHz (Dancer, 1981).

Interspecific differences in noise-susceptibility: a working hypothesis

On the basis of the above-mentioned results, it is striking to note that the differences in noise-susceptibility among species match pretty well the differences in auditory sensitivity. At 1 kHz the behavioral threshold is about 10 dB lower in the chinchilla than in the guinea pig and the squirrel monkey. At 1 - 2 and 4 kHz, behavioral thresholds are lower in the cat than in the guinea pig and the squirrel monkey. The most susceptible species (cat, chinchilla) are also the most sensitive.

In cat, chinchilla and man, Rosowski (1991) could demonstrate that the behavioral threshold is determined, throughout the auditory frequency range, by the amount of the acoustic power which is

transmitted from the free-field to the inner ear ($4x10^{-19}$ Watt in cat, $5x10^{-18}$ Watt in chinchilla and $1x10^{-18}$ Watt in man). For each species the shape of the behavioral audiogram depends almost entirely on the amplitude of the transfer function of the peripheral mechanical system (outer and middle ears). This means that the cochlea behaves like an acoustic power detector of constant sensitivity over the whole frequency range. Moreover, the absolute sensitivity of this detector seems to be almost the same in the three species studied by Rosowski, i.e. the auditory sensitivity of various animal species (at least in mammals) would differ only because of the acoustic characteristics of their peripheral mechanical system (Rosowski et al., 1986).

As the amplitude of the stimulus which enters the cochlea is species dependent and as the susceptibility to noise parallels the auditory sensitivity, could the cochlea of most of the animals used in auditory research (cat, chinchilla, gerbil, guinea pig...) *and of humans* present the same "resistance" to noise? If that is the case, the differences in susceptibility of the cochlea to noise would be solely due to the acoustic properties of the outer and middle ears (as pointed out by Drescher and Eldredge, 1974). This hypothesis is very simplistic but has a decisive advantage: it can be tested by comparing, in different species, the electrophysiological and morphological effects of given acoustic stimuli applied to the entrance of the cochlea. Of course it is quite out of the question for us to rule out the influence of other factors which act on the interspecific differences in susceptibility to noise! Micromechanics of the organ of Corti, blood flow in the inner ear, cochlear metabolism, influence of the efferent systems... play also very likely a role. Nevertheless, as a first step, it is necessary to assess the influence of the simplest parameters (the acoustic properties of the outer and middle ears) in order to determine the relative influence of the factors which belongs (i) to the peripheral mechanical system and (ii) to the auditory receptor.

Methods

A comprehensive experiment was conducted (i) to determine the physiological and morphological consequences of identical acoustic overstimulations in three species of mammals: cat, chinchilla and guinea pig and (ii) to relate the interspecific differences in noise susceptibility to the acoustic characteristics of the peripheral mechanical system (Décory 1989; Décory et al., 1992).

(i) To study the physiological and morphological consequences of overstimulations we proceeded as follows. The animals are deeply anaesthetized. The bulla is opened and an electrode is implanted on the round window. An earbar allows the insertion of different sound sources and a probe microphone is used to measure the acoustic level in front of the tympanum. A first audiogram is obtained in each animal by averaging Compound Action Potential (CAP) in response to tone-pips over the frequency range 1-32 kHz. Each animal is then exposed to a continuous 2, 4 or 8 kHz pure tone during 20 minutes. The level of this pure tone ranges from 82 to 132 dB SPL in front of the tympanum. Twenty minutes after the end of the stimulation another CAP audiogram is performed in order to obtain the short term Threshold Shifts (TS). Groups of 5 to 10 animals are used for each exposure condition. Immediately after the end of the second audiometry the cochlea is prepared for observation in Scanning Electron Microscopy (SEM); cochlear frequency maps for the cat (Liberman, 1982), for the chinchilla (Eldredge et al., 1981) and for the guinea pig (Cody et al., 1980) are used to relate anatomic location to stimulus frequency. All normal looking, altered and missing hair cells are counted.

(ii) In order to know to what extent the differences in susceptibility to noise are due to the characteristics of the peripheral mechanical system of each species, we measured the transfer function of the middle ear in the same experimental conditions. We recorded the acoustic pressure at the entrance to the cochlea (at the basal part of the scala vestibuli) as a function of the acoustic pressure applied in front of the tympanic membrane. Animals are prepared and the acoustic stimulation (pure tones from 0.1 to 20 kHz) is applied and controlled as previously. The intracochlear sound pressure measurements are performed using a miniature piezoresistive transducer equipped with a probe filled with silicon fluid (Dancer and Franke, 1980). A hole ($\approx$ 0.3 mm) is drilled into the scala vestibuli of the basal turn and the probe is put into place. The animal is then exposed to a frequency swept pure tone (100 Hz - 20 kHz).

Results

Short term TS have been measured in 40 cats, 84 chinchillas and 128 guinea pigs. About 200 cochleas have been observed in SEM.

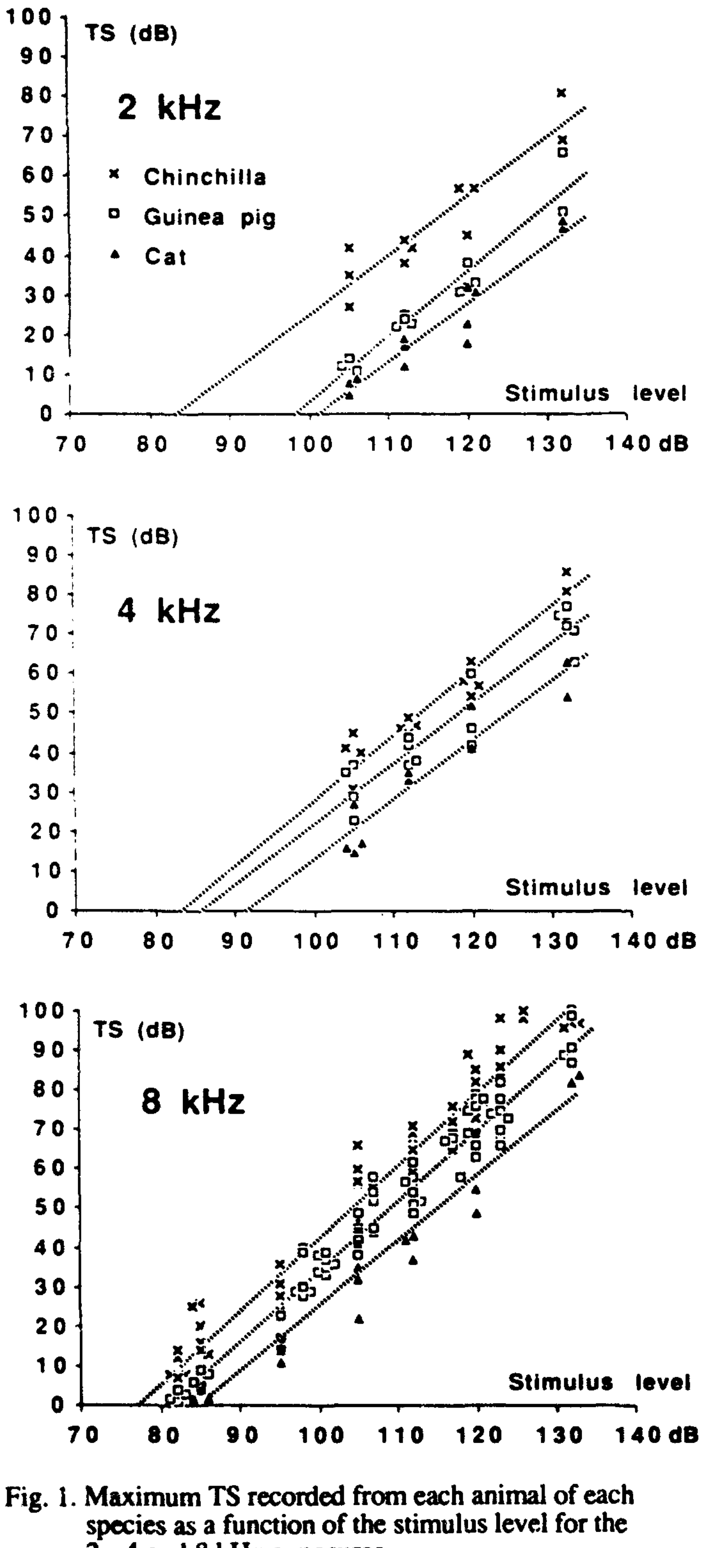


Fig. 1. Maximum TS recorded from each animal of each species as a function of the stimulus level for the 2 - 4 and 8 kHz exposures.
Dotted lines correspond to regression lines: r>0.9.

The maximum TS (20 minutes) recorded from each animal of each species as a function of the stimulus level (for the 2, 4 and 8 kHz pure-tone exposures) are shown on figure 1 (in any case the maximum TS shifts towards the high frequencies when the stimulus level increases: from +1/4 up to +2 octaves in comparison with the exposure frequency).

For all exposure conditions these findings indicate an increase in auditory susceptibility from the cat to the guinea pig and from the guinea pig to the chinchilla. The slopes of the regression lines are close from each other in all three species: about + 1.6 dB (TS) for each decibel of stimulus.

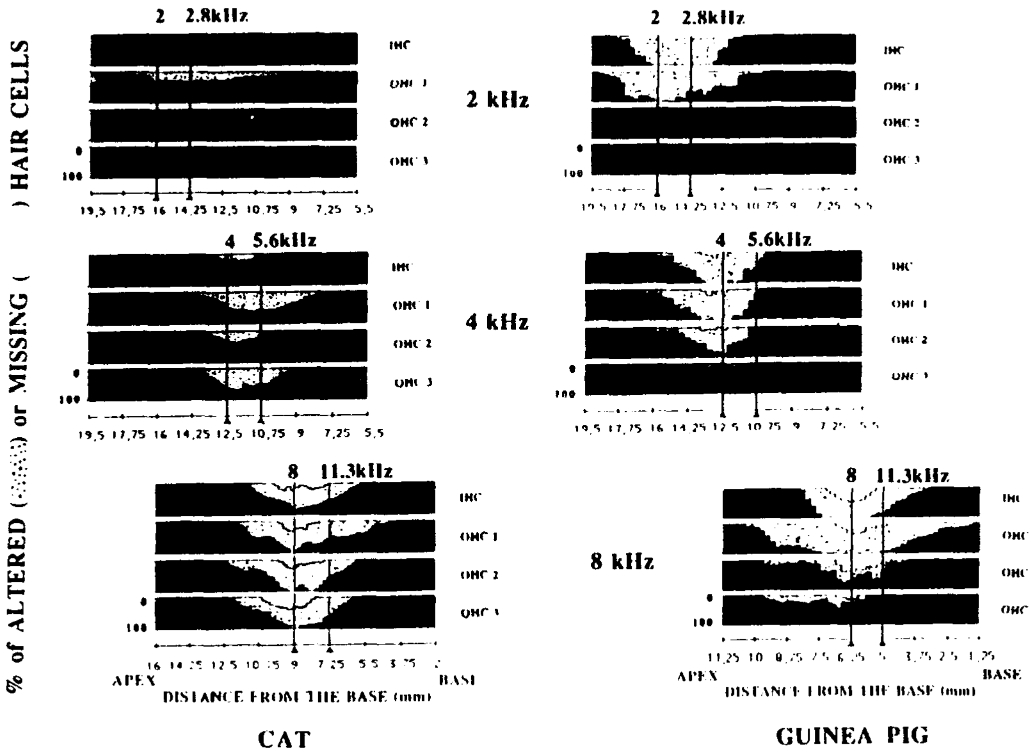
For a given stimulus level, the maximum TS increases with the exposure frequency.

When the exposure frequency is high, the TS are also more selective: we can define a Q_{20dB} which represents the ratio between the frequency for which the maximum TS is equal to 50 dB and the range of frequencies for which the TS vary from 50 to 30 dB. The values of this Q_{20dB} are almost the same in the three species (0.13 at 2 kHz, 0.3 at 4 kHz and 0.7 at 8 kHz); the higher the stimulation frequency, the smaller the frequency range of the audiogram affected by the acoustic stimulation.

Figure 2 shows the average SEM results obtained in the three species for the three exposure frequencies: 2, 4 and 8 kHz at 132 dB SPL for 20 minutes. Normal looking cells correspond to the black areas, cells with damaged stereocilia correspond to the dotted areas and missing cells to the white areas.

The amount of damage increases with the exposure frequency.

In the three species the first row of outer hair cells (OHC1) is the most sensitive, as described by Robertson and Johnstone (1980).



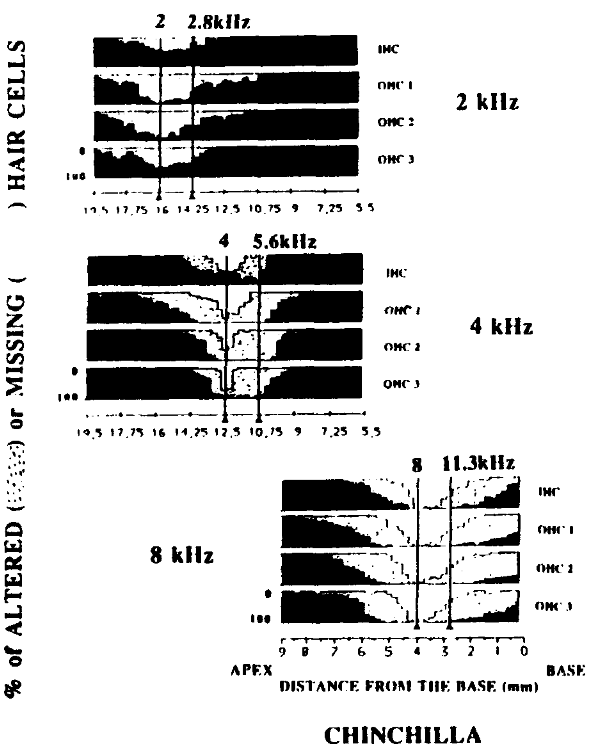


Fig. 2.
Average cochleograms obtained by Scanning Electron Microscopy in the cat, the guinea pig, and the chinchilla following exposure to pure-tones (2 - 4 and 8 kHz) at 132 dB SPL for 20 minutes.

At lower stimulations levels (112 and 120 dB), a 0.3 to 0.5 octave shift can be observed between the stimulation frequency and the characteristic frequency (CF) corresponding to the area of maximum stereocilia damage (Décory et al., 1992). At 132 dB (fig. 2) this shift disappears and missing hair cells are observed at a CF place corresponding to the stimulation frequency (Cody and Robertson, 1983).

For each exposure frequency (2 - 4 and 8 kHz) the morphological findings (fig. 2) confirm the general increase in auditory susceptibility from the cat to the guinea pig and from the guinea pig to the chinchilla.

In our study these differences can only be attributed to the conditions of transmission of the acoustic stimulus from the eardrum to the cochlea (and/or to the anatomical, mechanical, biochemical and physiological cochlear properties).

Interspecies differences in auditory susceptibility for a constant amplitude of the acoustic stimulus at the entrance to the cochlea:
The transfer function of the middle ear has been measured in 8 cats, 9 chinchillas and 11 guinea pigs (animals are prepared and the acoustic stimulation is applied and controlled as previously) (Décory et al., 1992). Between 500 Hz and 10 kHz the amplitudes are very close in the three species: the observed differencies are lower or within one standard deviation (<10 dB). The amplitude is maximum (31 to 33 dB) between 600 Hz in the cat and the chinchilla and 1.2 kHz in the guinea pig.

With the help of these recordings we can compare the TS measurements (i.e., threshold of TS, isomaximum TS) and the SEM observations (i.e., threshold of stereocilia damage, isocellular injury) from one species to another for a given amplitude of the acoustic stimulus at the entrance to the cochlea. In these conditions the interspecific differences are especially noticeable between the cat (which looks to be less sensitive) and the two other species and less remarkable between the chinchilla and the guinea pig.

Interspecies differences in auditory susceptibility for a constant acoustic power at the entrance to the cochlea:
It is also possible to compare the interspecific differences as a function of the amount of mechanical energy dissipated by unit of time inside the cochlea (Décory, 1989; Décory et al., 1992) (Table I).

	2 kHz	4 kHz	8 kHz
Cat	$3.3 \cdot 10^{-9}$	$7.0 \cdot 10^{-9}$	$2.5 \cdot 10^{-9}$
Chinchilla	$8.4 \cdot 10^{-9}$	$6.3 \cdot 10^{-9}$	$3.5 \cdot 10^{-9}$
Guinea pig	5.1 to $12.8 \cdot 10^{-9}$	1.1 to $3.2 \cdot 10^{-9}$	1 to $2.4 \cdot 10^{-9}$

Table I: Acoustic power entering the cochlea (in Watt for a level of 1 Pascal at the tympanum)

These results show that, in our experimental conditions and for a given sound pressure level at the tympanum, the acoustic power entering the cochlea is very similar in the three species and for the three exposure frequencies. We can evaluate the acoustic power corresponding to different damage criteria (threshold of the TS, iso-maximum TS, threshold of the stereocilia damages and iso-cellular injuries). These evaluations show that (i) the acoustic power which corresponds to a given damage criterion decreases strongly when the stimulation frequency increases, (ii) the values of the acoustic power are very close between the chinchilla and the guinea pig whereas they are much larger in the cat (Table II).

	2 kHz	4 kHz	8 kHz
Cat	$530 \cdot 10^{-8}$	$120 \cdot 10^{-8}$	$20 \cdot 10^{-8}$
Chinchilla	$190 \cdot 10^{-8}$	$17 \cdot 10^{-8}$	0.7 to $1.3 \cdot 10^{-8}$
Guinea Pig	80 to $210 \cdot 10^{-8}$	7 to $20 \cdot 10^{-8}$	0.6 to $1.5 \cdot 10^{-8}$

Table II: Acoustic power entering the cochlea (in Watt) and corresponding to the threshold of the stereocilia damages (for a 20 minutes exposure)

The cochleas of the chinchilla and the guinea pig have about the same susceptibility whereas the cochlea of the cat is more resistant and this difference corresponds to about 6 dB in stimulation level. This phenomenon seems to have a cochlear origin (the influence of the acoustic reflex of the middle ear can probably be ruled out because all our animals are deeply anaesthetized and Møller, 1974, has shown that this reflex is ineffective beyond 1.5 kHz in the cat; the same observation has been made by Avan, 1992, in the guinea pig).

If the transfer function of the peripheral mechanical system (external and middle ears) seems to be responsible for a large part of the interspecific differences in noise susceptibility, there are certainly cochlear factors which are of some importance.

Cochlear factors

The activity of the efferent feed-back controlling the outer hair cells (OHC) could explain some of the interspecific differences in susceptibility to noise. However, there is a controversy about the efficiency of this mechanism: Liberman (1992) has demonstrated that there is no protective effect in the cat, whereas Rajan (1992) has observed a significant influence in the guinea pig.

Without ruling out many other possibilities such as vascular, metabolic, biochemical phenomena... (which were out of our experimental capabilities), and because it is generally agreed that the displacements of the stereocilia are at the onset of the auditory damages (Saunders and Flock, 1986), we looked at the cochlear mechanical events which could explain the interspecific differences in noise susceptibility. Using anatomical measurements performed by various authors we designed a schematic model of the Corti's organ in each species (fig. 3) and we evaluated the angular displacements of the stereocilia as a function of the displacements of the basilar membrane, for three locations corresponding to characteristic frequencies (CF) of 1 - 4 and 16 kHz (Décory et al., 1992).

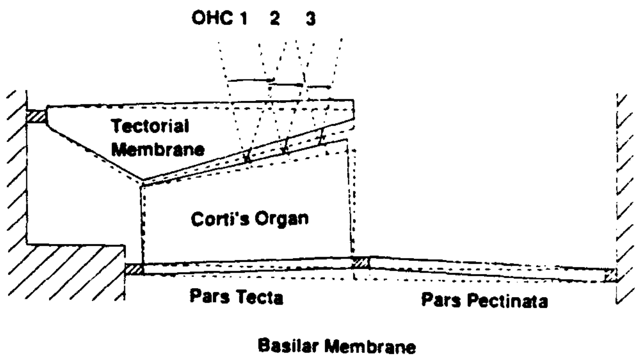


Fig. 3.
Schematic representation of the organ of Corti

Several observations can be made:
(i) the shorter stereocilia of the first row of the outer hair cells (OHC 1) undergo the largest angular displacements: this could explain the high susceptibility of these cells to acoustic injury (fig. 2),
(ii) for a given input to the cochlea, the angular displacements of the stereocilia (induced by the displacements of the basilar membrane) are comparable in the chinchilla and in the guinea pig but about two times smaller in the cat. *Thus we could hypothesize that the smaller susceptibility of the cat's cochlea is due to a smaller angular displacement of its OHC stereocilia.*

Moreover, the stereocilia damages could be considered to occur according to a fatigue failure process. In this case, the amplitude and the number of cycles undergone by a stereocilia would be of importance. In support of this hypothesis we observed that close to the base of the cochlea of a given species, for a given amplitude of the signal at the entrance to the inner ear and for the frequencies lower than CF, the higher the stimulation frequency, the higher the damages (though the displacement of the basilar membrane and the angular displacement of the stereocilia are the same: Décory, 1989). To maintain a given amount of damages the acoustic input to the cochlea has to be increased by 10 to 15 dB each time the stimulation frequency is halved. These observations could be explained by the stress sustained by the stereocilia which depends (on a nonlinear way) on the number of cycles (fatigue failure phenomenon).

Conclusion

The conditions according to which the acoustic stimulus is transmitted from the free field to the inner ear seem to be responsible for the largest part of the interspecific differences in auditory susceptibility. Cochlear factors of mechanical origin could explain part of the higher resistance which is observed in some species. These studies are essential if one searchs for the possibility to extrapolate NIHL measurements performed on the animals to humans and to improve the usefulness of the animal models.

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RECENTS ADVANCES IN COCHLEAR NEUROBIOLOGY: COCHLEAR EFFERENTS AND ACOUSTIC TRAUMA

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ABSTRACT

One area of fundamental and clinical importance is the relationship between the temporary (TTS) and permanent (PTS) threshold shift induced by acoustic overstimulation. The purpose of the present paper is to relate functionnal and ultrastructural changes associate with various types of acoustic trauma and to determine which abnormalities (mechanical and/or neuronal damages) are responsible for the presence of TTS and/or PTS.

When a moderate tonal stimuli (6kHz, 95 dB SPL, 15 min.) was apply in guinea pig, both electrophysiological responses and the distortion product otoacoustic emissions (DPOAEs) recorded 15 min. after noise exposure, showed a maximum hearing loss, half an octave above the exposure frequency, and no greater than 30 dB. In addition, no obvious ultrastructural abnormality could be seen and full recovery was observed 24 hours later. When strychnine which is known to block the effects of an electrical stimulation of the medial efferents, was applied intracochlearly during sound exposure, the maximum CAP threshold shift was significantly greater (about 12 dB) than that observed in animals exposed to intense sound during perfusion with artificial perilymph alone. Altogether, these results suggest that 1) moderate acoustic trauma affects active mechanisms responsible for the generation of the otoacoustic emissions and 2) one effect of the medial efferents connect to the OHCs may be to act as protectors against acoustic overstimulation.

When the animals was exposed to more intense sound (6kHz, 130 dB SPL, 15 min.), the hearing loss was greater than 60 dB, and a partial recovery (about 40 dB) was observed 14 days latter. Histological examination immediately after acoustic trauma showed, behind outer and inner hairs cells damages, a drastic swelling of the radial afferent dendrites under the IHCs with a loss of intradendritic content and membrane disruptions. Fourteen days later, while some hair cells damages remained, the IHCs was fully reconnected by the radial afferent dendrites, suggesting that, a part of the threshold recovery was due to the synaptic plasticity these fibers. Supporting the assumption that a part of the threshold shift was due to radial afferent swellings, glutamate antagonists, applied intracochlearly during sound exposure, reduced the effects of acoustic trauma and completely protected the radial dendrites. Preliminary data attesting the involvement of the lateral efferents in the protection of the radial afferent dendrites in such physiopathological conditions are also presented.

INTRODUCTION

The cochlea coiled up in spiral is the auditory part of the inner ear. Within the cochlea, the organ of Corti possesses two types of hair cells: the inner hair cells (IHCs) and the outer hair cells (OHCs). The IHCs, the classical mechanotransducers, are connected to 95 % of the auditory nerve afferent fibers. In contrast, the outer hair cells are only innervated by 5 % of afferents which are not responsive to sound (Robertson, 1984). One current hypothesis is that the fast motility of the isolated OHCs is related to the exquisite sensitive and discriminative properties of the auditory receptor, by enhancing the vibration of a narrow region of basilar membrane. In addition, the cochlea is innervated by two efferent systems: 1) the lateral efferent system coming from the lateral superior olive which modulates the activity of the auditory nerve dendrites below the IHCs and 2) the medial efferent system coming from medial nuclei of the superior olivary complex which modulates the OHCs (see for review Warr et al., 1986).

Hearing deficits induced by exposures to intense acoustic stimulation have been extensively documented. For instance, it is well known that, when the threshold shift is no greater than 40 dB, the maximum hearing loss can be detected half an octave above the exposure frequency and the hearing loss can be recovered. This effect is commonly named temporary threshold shift (TTS) or auditory fatigue. When the threshold shift is highest, it cannot be completely recovered, and permanent threshold shift (PTS) is observed (see for review: McFadden, 1986). In this paper, we report that a continous pure sound at 6 kHz presented during 15min at 95 dB SPL, induces a largest threshold shift at 8.4 kHz (half an octave above the exposure frequency) and this loss recovers 1 day later (fig; 1) which is consistent with previous works (Mitchell *et al.*, 1977, Puel et al., 1988a, 88b). Increasing the sound exposure intensity to 130 dB SPL, resulted in the largest threshold shift up to half an octave above the exposure frequency and the first appearence of PTS 14 days later (fig. 3). In the same way, it has been demonstrated that stereocilia lesions and hair cell degeneration result to PTS. The hair cell damages was first incurred in the first row of the OHCs, then in the IHCs and subsequently in the second and the third row of OHCs (See for review: Saunders *et al.*, 1985). Behind this mechanical damage, it is known that acoustic trauma also induces swelling of the dendrites at the level of the IHCs (Beagley, 1965; Spoendlin, 1971; Robertson, 1983, Pujol, 1991). The IHCs of the cochlea likely use an excitatory amino acid, probably L_glutamate or an analog, as a neurotransmitter (Eybalin et al, 1983). Since dendritic swelling resulting from glutamatergic agonist excitotoxicity have been observed at the radial afferent fibers level below the IHCs (Pujol et al., 1985; Janssen and Jensen, 1988; Juiz et al., 1989, Gil-Loyzaga and Pujol, 1990; Puel et al., 1991), it can be speculated that acoustic trauma-induced swelling of the afferent dendrites below the IHCs is due to an excess of the release and/or a dysfunction of the uptake mechanism of extracellular glutamate (Pujol, 1991).

One area of fundamental and clinical importance concerns the relationship between the TTS and PTS. Therefore, the purpose of the present paper is to relate functionnal and ultrastructural changes associate with various types of acoustic trauma and to determine which abnormalities (mechanical and/or neuronal damages) are responsible for the presence of TTS and/or PTS.

EFFECTS OF ACOUSTIC TRAUMA ON THE COCHLEAR MICROMECHANICS.

It has been proposed that, within the cochlea, an active mechanical processes improve the low-level sensitivity and sharpness of tuning by enhancing the vibration of the basilar membrane (see for review Gold, 1948, Davis, 1983; Neely and Kim, 1983; Dallos, 1985; Kim, 1986; Mountain, 1986). These active mechanical processes, which probably underlie the fast motility of the isolated OHCs (Brownell *et al.*, 1985; Ashmore, 1986), induce non-linear responses leading to the modification of the acoustic signal and created additional frequencies. Traditionally, when the ear is stimulated by two continous pure tones, or primaries (f1 and f2, with f1<f2), the cochlea generates distortion products (f_2-f_1, $2f_1$-f_2, $3f_1$-f_2...) which can be easily recorded in the external ear canal. This phenomenon is called distortion product otoacoustic emissions (DPOAEs). Studies in the cat (Kim, 1980, Kim et al, 1980), chinchilla (Kim, 1980, Zureck et al, 1982), gerbil (Schmiedt and Adams, 1981, Schmiedt and Addy, 1982) and human (Kemp, 1979; Wilson, 1980; Witt et al, 1981) have shown that the most prominent distortion products occur at the frequency 2f1-f2. However, the relation between the 2f1-f2 DPOAEs and auditory sensitivity is not, however, clearly established. Actually, the detection threshold for 2f1-f2 DPOAEs depends almost entirely on the noise floor and the sensitivity of the recording equipment used. Therefore, most authors study the 2f1-f2 DPOAEs at suprathreshold levels rather than at the "threshold" itself and little is known about the responses associated with low-level stimuli. There is not doubt that the site of generation of DPOAEs is in frequency region of the primaries. However, some authors used f2 (Kemp and Brown, 1984) rather than f1 (Brown and Gaskill, 1990, Gaskill and Brown, 1990) has an indicator of auditory sensitivity , while others suggest that the geometric means of f1 and f2 ($\sqrt{f1*f2}$) is a more appropriate index (Martin et al., 1987; Longsburry-Martin et al., 1990a,b, Martin et al, 1990). Consequently, although several studies have reported progress in the systematic measurement of DPOAEs and its correlation with auditory sensitivity in both animals (Kemp and Brown, 1984; Martin et al., 1987; Brown and Gaskill, 1990, Gaskill and Brown, 1990) and humans (Longsburry-Martin et al. 1990a,b, Martin et al, 1990; Brown and Gaskill, 1990), more information is needed to evaluate the clinical potential of these measurements. Therefore, this study has led to the proposal that 2f1-f2 DPOAEs could be an objective, although indirect, test of auditory sensitivity, by comparing in the guinea pig, the effect of moderate sound exposure known to induce TTS (6 kHz, 95 dB SPL during 15 min, Mitchell et al., 1977) on the electrophysiological auditory nerve responses [Compound action

potential (CAP) or auditory brainstem responses (ABRs)] and on the DPOAEs [egal primary level (L2=L1) and a ratio (f2/f1) egal to 1.17]. Moreover, since DPOAEs reflect the mechanical non-linearity of the cochlea, this comparison could allow us to evaluate the ultrastructural damages (mechanical and/or neural) involved in TTS.

Electrophysiological measurements shows that moderate sound exposure induced a largest hearing loss at a frequency situated half an octave above the exposure frequency (8.4 kHz, fig. 1). When compared with the DPOAEs "threshold", the same amount of TTS was observed (about 25 dB). It is interesting to note that the more appropriate index is f2 rather than the geometric mean of the primaries ($\sqrt{f1 * f2}$). Actually, the maximum threshold shift was respectively 8.4 kHz and 7.7 kHz when we used f2 and $\sqrt{f1 * f2}$ as an indicator of hearing sensitivity. Examination of the reduction of the amplitude of the DPOAEs as a criterion showed a good correlation with auditory sensitivity measurements for primary intensities as high as 62 dB SPL. However, for higher stimulation intensities, no corellation between the electrophysiological responses and DPOAEs was detected (data not shown). In any case, both electrophysiological and DPOAEs responses recover 1 day later (fig. 1). Therefore, these results suggest 1) that a moderate sound exposure induces an alteration of the micromechanical properties within the cochlea which can recovers one day later 2) that, 2f1-f2 DPOAEs (f2/f1=1.17 and L1=L2) for low level stimuli stimulus can be used to evaluate the auditory function using f2 as an indicator. Consistent with this assumption, no dendritic swelling below the IHCs could be seen in transmission electron microscopy. In addition, no ultrastructural abnormality within the hair cells could be noted, suggesting that subtle changes had occurred. Among the OHCs. the stereocilia of the first row are more stiff than those in the second and in the third row. The IHCs stereocilia exibited about the same stiffness as those of the second row of OHCs (Strelioff and Flock, 1984, Saunders and Flock, 1986, Saunders et al, 1986a,b). Therefore, one possibility could be that such moderate exposure might reduce the stiffness of stereocilia which might be recovered after a period of rest. Futher experiments will be necessary to explore the mechanism involved in the TTS.

PROTECTIVE EFFECTS OF MEDIAL EFFERENTS DURING ACOUSTIC TRAUMA.

A current hypothesis is that while the electrically induced fast motility of the isolated OHCs is related to the mechanical active processes (Brownell *et al.*, 1985; Ashmore, 1987), the chemically induced slow motility of the OHCs is related to the modulation of the active processes which is probably driven *in vivo* by the efferent fibers. The only efferents connected to the OHCs are the medial olivocochlear (MOC) efferents coming from the medial nuclei of the superior olivary complex (see for review Warr *et al.*, 1986). Electrical stimulation of the crossed olivocochlear bundle (COCB), which essentially activates the MOC efferents, has been demonstrated to reduce the effect of intense sound on the cochlear potentials (Rajan, 1988a;b). Therefore, one suggestion is that the MOC efferents might protect the cochlea against the

damaging effects of intense sound exposure. Since strychnine has been shown to block the effects of an electrical stimulation of the COCB (see for review: Wiederhold, 1986), we decided to test the protective role of MOC efferents by comparing the TTS induced by sound exposure during intracochlear perfusion of artificial perilymph with and without strychnine (fig. 2).

Our results show that in the group of animals exposed to an intense sound during perfusion with artificial perilymph containing 10 uM strychnine, the shift in CAP threshold at 8,4 kHz exposure was significantly greater (about 12 dB, fig. 3) than that observed in animals exposed to intense sound during perfusion with artificial perilymph alone. The present result thus suggests that a protective intracochlear mechanism is mediated by the activation of the crossed MOC efferents during intense sound stimulation. This activation constitutes at least one way through which a protective mechanism may be expressed during intense sound stimulation of the cochlea.

EFFECTS OF ACOUSTIC TRAUMA ON THE RADIAL AFFERENT DENDRITES.

The cochlea exposed to the pure sound frequency of 6 kHz for 15 min at an intensity of 130 dB SPL, showed the largest threshold shift up to half an octave above the exposure frequency and the first appearence of PTS centered on the sound exposure frequency 14 days later (fig.4). Immediately after this sound exposure, transmission electron microscopy shows in the basal turn traumatized area a massive swelling of afferent dendrites below the IHCs (fig. 5a). In addition, while some OHCs of the first row were drastically damaged (i.e. swollen nucleus and vacuolized cytoplasm; fig5 c), few abnormalities was seen at stereocilia level (fig. 5d). Particulary striking is the exceedingly high density of the synaptic vesicles in the medial efferent terminals, whereas the spiral afferent endings look normal (fig. 5c,e), suggesting a very intense metabolic and/or functional activity of these efferents. Altogether, these results suggest that the threshold shift induced by such acoustic trauma is due 1) to neural damage at the dendritic level below the IHCs, and 2) to the mechanical damage at the OHCs level. However, while hair cell damage were still persisted, a complete reconnection of the IHCs by the afferent auditory dendrites was observed 14 days later. In order to investigate the contribution of dendritic swelling in the initial threshold, we perfused kynurenate during the 130 dB SPL sound exposure. Due to the fact that kynurenate postsynaptically blocks the action of the afferent neurotransmitter (i.e. glutamate, Bobbin and Ceasar, 1987), it also blocks the cochlear efferent loop, thus increasing the mechanical damage as shown above. Therefore, strychnine (10 μM) was added both to control cochleas which had been perfused with artificial perilmph and to cochleas perfused with kynurenate. Our results show that in the group of animals exposed to an intense sound during perfusion with artificial perilymph containing 5 mM kynurenate + 10 μM strychnine, the shift in CAP threshold was significantly less (about 20 dB between 6 and 15 kHz) than those observed in animals exposed to intense sound during perfusion with artificial perilymph containing only strychnine (fig. 4). Consistent with these electrophysiological results, no dendritic swelling was observed (fig. 5b) in these kynurenate-perfused cochleas. This absence of swelling in kynurenate-treated cochleas

suggests that cochlear damages resulting from acoustic trauma could be linked to glutamate excitotoxicity. It can therefore be postulated that intense sound exposure induces an excess of release and/or a dysfunction of the uptake mechanism of extracellular glutamate (Pujol, 1991). It is however interesting to note that after 14 days no dendritic swelling could be also observed in the non-treated cochlea, attesting that reconnection of the IHCs by the dendrites of the auditory neurons has occurred. However, this type of neuronal plasticity does not (necessarily) account for [illegible] the recovery observed. Actually, although kynurenate perfusion reduces the effect of severe acoustic trauma, this threshold shift was far higher than the shift observed 14 days later (fig. 4), indicating a partial mechanical repair had also occurred as suggested above with more moderate sound exposure.

PROTECTIVE EFFECTS OF LATERAL EFFERENTS DURING ACOUSTIC TRAUMA.

The physiological activity of the radial afferent fibers connected to the IHCs is probably modulated by the lateral efferent innervation. Immunocytochemical studies reported the presence of neuroactive substances such as acetylcholine, GABA, calcitonin gene-related peptide and certain opioid peptides like, enkephalins and dynorphins in the cochlea (See for review; Eybalin., 1992). Although the functional role of these substances need to be clarified, some recent electrophysiological results show that the intracochlear perfusions of 0.01 to 1 mM of piribedil, a D2 dopaminergic agonist caused a dose-dependent reduction of the amplitude of the compound action potential and an increase of its N1 latency, predominantly at high intensity of stimulations (Puel et al, 1993). This suggests a modulatory action of dopamine via D2 receptors upon the radial afferent dendrite. Since, this inhibitory action was predominant at high intensity sound stimulations, one suggestion is that dopamine could be involved during acoustic trauma, as a lateral efferent transmitter or modulator. Consistent with this assumption is a release of dopamine in rat cochleas submitted to different intensities of noise (Gil-Loyzaga et al, 1991). In addition, when 1 mM of piribedil was perfused in the cochlea prior to a 10 minutes period of ischemia, clear protection of the radial dendrites against the ischemia-induced swelling was observed (Pujol et al., 1993). Further experiments need to be done to confirm the protective effect of the dopaminergic lateral efferents against acoustic trauma-induced swelling.

In conclusion, it seems that the recovery of the threshold after acoustic trauma involved, at least, two different mechanisms. Firstly, a neuronal plasticity leading to the reconnection of the IHCs by the dendrites of the auditory neurons and secondly, mechanical repair accounting for recovery after both moderate and intense exposure. In both cases protective intracochlear mechanisms against an intense sound may be mediated by an activation of cochlear efferents, i.e the medial efferents connected to the OHCs to reduce the mechanical damages at the hair cells level and the lateral efferents to protect the radial afferents below the IHCs.

Acknowledgements

The authors wish to thank Prof. R.P. Bobbin who initiated this work, M. Lenoir for helpful discussions concerning the manuscript, C. Gervais d'Aldin who did some of the experiments, and S. Ladrech, R. Leducq and F. Tribillac for technical assistance. They also thank P. Sibleyras for photographic work and E. Mayat for editorial assistance.

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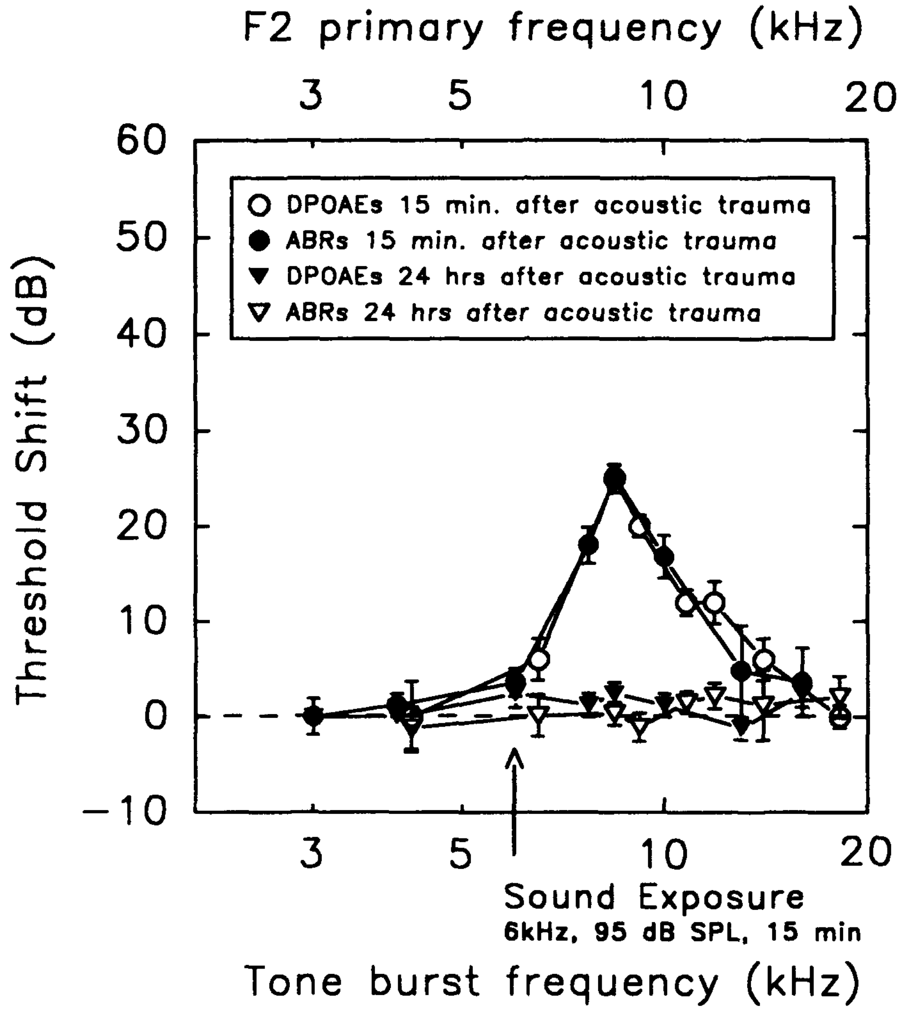


Figure 1 - ABRs and 2f1-f2 DPOAEs threshold shift in dB (mean ± SEM) as a function of tone frequency after acoustic trauma (6 kHz, 95 dB SPL, 15 min). Shown are ABRs threshold shift recorded 30 min. (n=10, filled circle) and one day (n=10, filled triangle), and 2f1-f2 DPOAEs threshold shift recorded 30 min. (n=8, open circle) and one day (n=8, open triangle) after exposure.

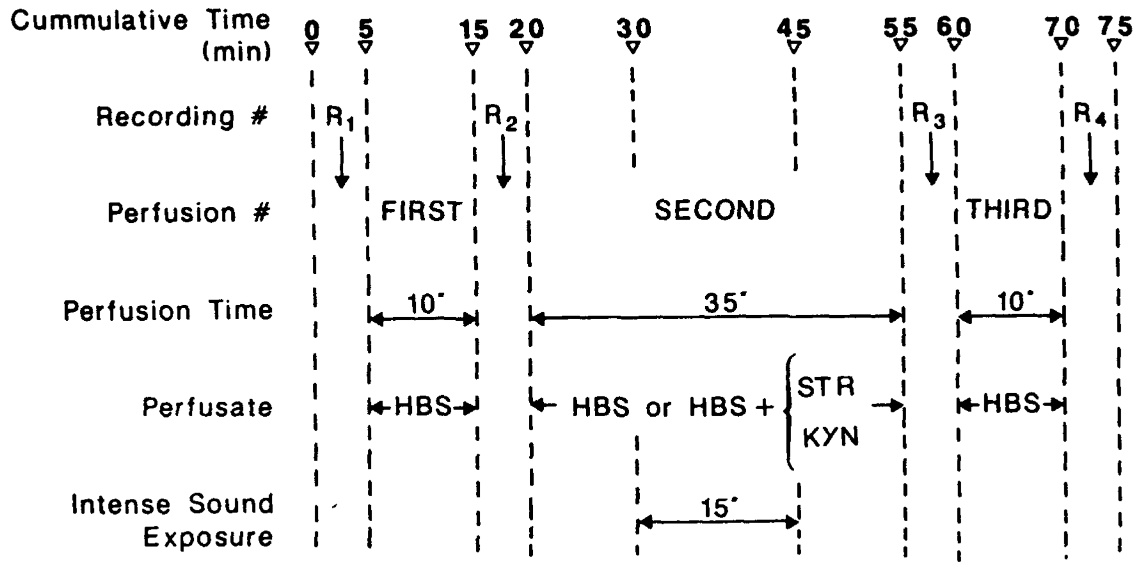


Figure 2 - Schematic of the timing of events for the experiments (from Puel et al., 1988a). Artificial perilymph (Hepes Buffered Saline, HBS) was infused into the basal turn scala tympani and allowed to flow out of the basal turn scala vestibuli at 2.5 ul/min through holes made in the cochlea. The artificial perilymph solution had the following composition: 137 mM NaCl; 5 mM KCl; 2 mM $CaCl_2$; 1 mM $MgCl_2$; 10 mM Hepes; 10 mM glucose, pH 7.4. The final osmotic pressure was adjusted (305/310) by adding NaCl. Three consecutive intracochlear perfusions of different durations were carried out in all animals, the first of 10 min, a second of 35 min and a third of 10 min. In all animals artificial perilymph was perfused for 10 min. This was then followed by the second perfusion of 35 min consisted of artificial perilymph alone, artificial perilymph containing 10 uM strychnine sulfate and/or 5 mM kynurenate. Starting 10 min after the beginning of the second perfusion period a 6 kHz, 15 min continuous tone was presented at 95 or 130 dB SPL to the ear. In all animals after the second perfusion period, the third perfusion was finally carried out with artificial perilymph. Compound action potentiel (CAP) or auditory brainstem responses (ABRs) thresholds were recorded before any perfusion and immediately after each perfusion.

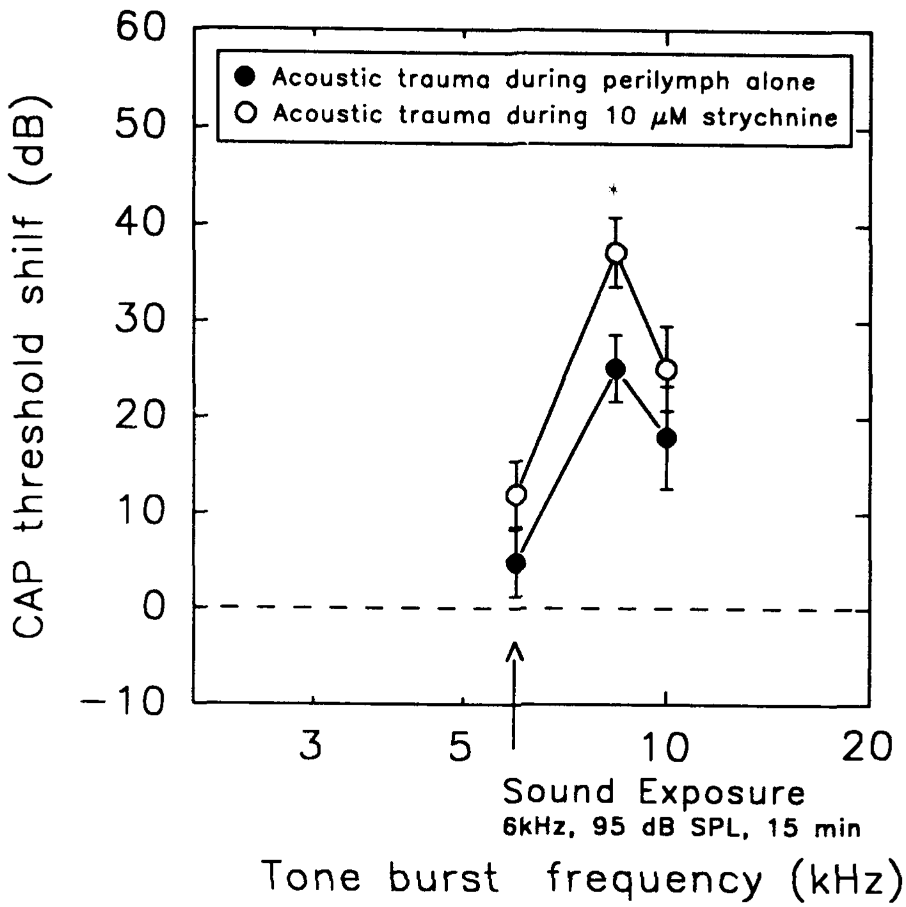


Figure 3 - CAP threshold shift in dB (mean $\pm$ SEM) as a function of tone frequency after acoustic trauma (6 kHz, 95 dB SPL, 15 min) recorded after the end of the third perfusion (from Puel et al., 1988b). The threshold shift was recorded as the difference from the recording after the first perfusion with artificial perilymph and the recording after all perfusions. Shown are data obtained after intense sound exposure during perfusion with artificial perilymph alone (n=5, filled circle) and during perfusion with artificial perilymph containing 10 μM strychnine (n=5, open circle). Analysis of variance and Newmann-Keuls multiple range test were used to determine significance (*P < 0.01).

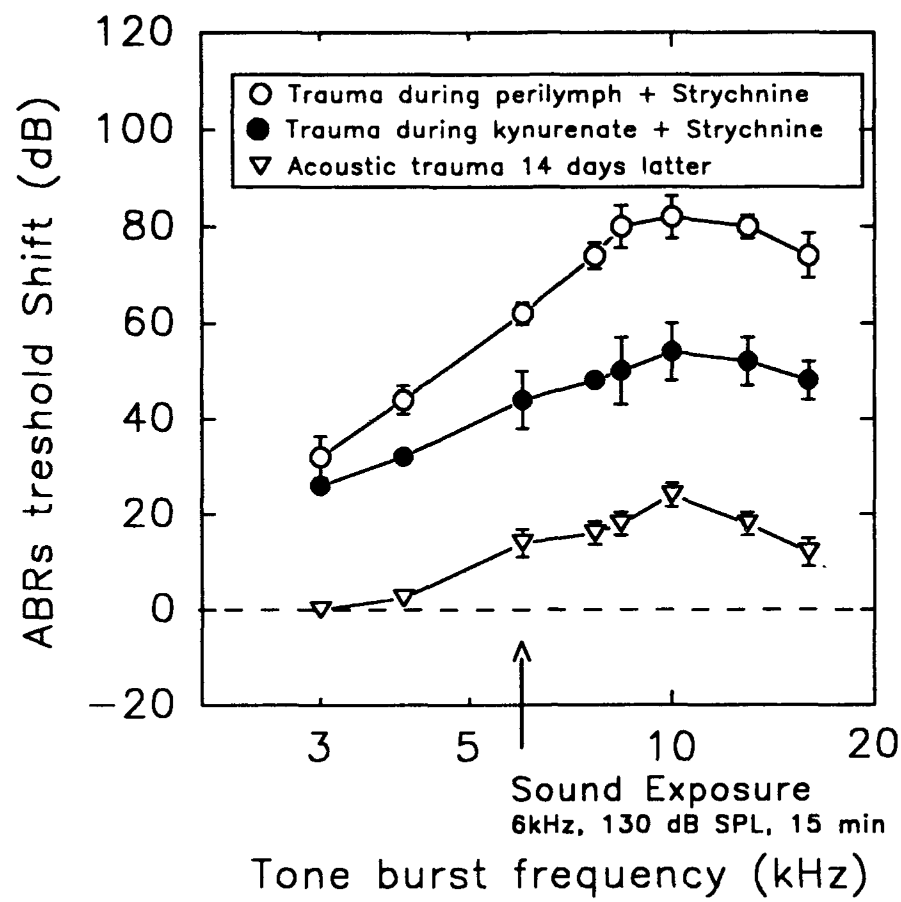
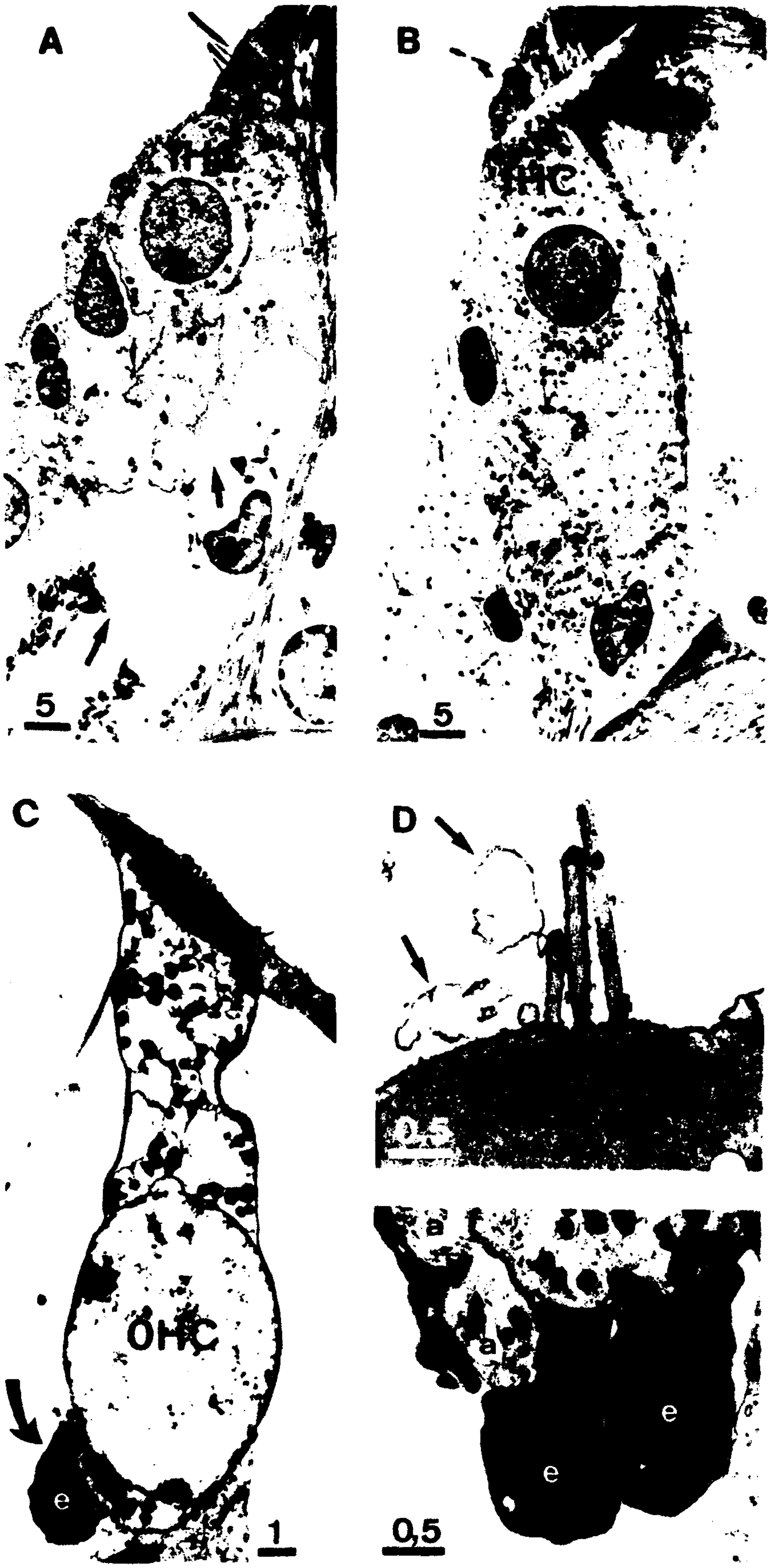


Figure 4 - ABRs threshold shift in dB (mean + SEM) as a function of tone frequency after acoustic trauma (6 kHz, 130 dB SPL, 15 min) recorded after the end of the third perfusion. The threshold shift was recorded as the difference from the recording after the first perfusion with artificial perilymph and the recording after all perfusions. Shown are data obtained after intense sound exposure during perfusion of artificial perilymph containing 10 µM of strychnine (n=3, open circle), during perfusion of artificial perilymph containing 5 min. kynurenate + 10 µM of strychnine (n=3, filled circle), and 14 days after acoustic trauma (n=3, open triangie).


A
5
B
IHC
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C
OHC
e
1
D
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a
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e
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Figure 5 - Transmission electron microscopy after sound exposure (6kHz, 130 dB, 15 min).

A and **B**: inner hair cell (IHC) 15 min after intense sound exposure. **A)** Shown a low magnification of an IHC from a control cochlea, i. e. perfused with artificial perilymph containing 10 µM strychnine. The acoustic trauma induced a dramatic swelling of radial afferent dendrites which resulted in an indentation of the IHC basal pole. This massive swelling of the radial afferent dendrites underneath the IHCs was followed by a total membrane disruption (arrows). **B)** In cochleas perfused with artificial perilymph containing 5mM Kynurenate + 10 µM strychnine, no sign of dendritic swelling was found at the IHC base. Note that no apparent damages can be seen in the IHC in both conditions.

P: inner pillar cell. Bar: 5 µm.

C, **D** and **E**: outer hair cell (OHC) 15 min. after intense sound exposure. **C)** Shown a low magnification (Bar: 1µm) of an damaged OHC from the first row basal turn with a swollen nucleus and vacuolized cytoplasm. Note at the base of the cell a dark efferent terminal (curved arrow). **D)** A higher magnification (Bar: 0.5µm) of the apical pole of the OHC show, despite the presence of additional membrane (arrows), that the stereocilia are still well erected. **E)** high magnification (Bar: 0.5µm) of the synaptic pole of the OHC showing two dark efferent endings (e) with very high density of microvesicules and two apparently normal afferent terminals (a).

CURRENT EXPOSURE STANDARDS; INTERACTION OF EXPOSURES; SUSCEPTIBILITY AND VULNERABILITY

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Abstract

Three of the major mistakes made by ISO 1999 are: (1) the Hearing Threshold Levels (HTLs) of 18-year-olds entering the work force are assumed to be 0 dB; (2) impulse noise is assumed to be equally hazardous as steady and impact noises; and (3) in adopting the equal-energy (total daily energy) principle, the effect of temporal pattern is ignored. Recent research dealing with the first and third of these errors is discussed. Also reviewed are developments in susceptibility and vulnerability to NIPTS.

Exposure Standard ISO 1999

One of the most significant and far-reaching developments in the last five years was the confirmation of ISO 1999 as representing the expected relation between exposure to noise and the resultant permanent threshold shift (PTS). ISO 1999 has numerous shortcomings, but three are probably the most important. First, by adopting the principle that equal amounts of A-weighted energy in a day or a week are equally hazardous, it ignores the role of intermittence. A related drawback is that impulse noise is treated as just another noise source contributing to the daily exposure rather than an event requiring special consideration other than limiting exposure to 140 dB SPL peak. These deficiencies can be accepted on humanitarian grounds, as they are overprotective of hearing. A third drawback, however, is one that serves no useful purpose and leads to erroneous estimates of hazard: a confusion of the terms PTS and HTL.

The HTL (H') of a group of workers is defined as the sum of two quantities H and N, where N is the NIPTS to be expected from the noise exposure and H is "the HTL, in dB, associated with age (HTLA)", minus a correction factor, -HN/120, that takes into account the fact that there is only so much hearing that can be lost. The source of difficulty here is H: there is no such entity as "the HTL associated with age". Had H been defined as "the <u>change</u> in HTL associated with age", as it should have been, because that is how Spoor developed the "age correction" curves, it would have been apparent that an additional term should be included in the formula for H': i.e., H_0, the original HTL before either "aging" or noise had any effect, should also be subtracted, viz., $H'=H+N-H_0-HN/120$. Actually, what ISO 1999 does is to assume that H_0 is zero--i.e., that at age 18, everyone has 0 dB HTL, as defined in ISO 389, at all frequencies. However, audiometric zero was based on audiograms from a highly selected population of 18-year-olds; anyone with exposure to sociacusic and nosoacusic influences was eliminated, and also individuals whose thresholds, despite a negative history of nosoacusis and sociacusis, were "obviously not normal". There is ample evidence, the most recent of which is summarized below, that H_0 is not zero, so that anyone who uses the ISO 1999 formula to predict N will be in error by approximately a factor of H_0. Therefore the expected N will be underestimated, the actual NIPTS will be greater than this prediction, and the user will conclude incorrectly that the workers' noise is hazardous.

The Additivity of Noise and Other Causes of Hearing Losses

Before turning to the question of what H_0 should be, let us consider the general problem of the interaction of noxious influences. If two or more agents operate on a system, what can one expect to be the result of their combination? For uncomplicated interactions, one simple answer is reasonable: if the agents operate on completely different parts of the system, the effects will add; if they operate on exactly the same part of the system, effectivenesses will add. Additivity of effect in the auditory system is exemplified by conductive and sensory hearing losses. If the transmission of sound through the middle ear is reduced by 10 dB, due perhaps to otitis media, then an individual who also has a sensory loss due to noise exposure, say 30 dB, will indicate a threshold of 40 dB HTL (but only, of course, if he began life at 0 dB HTL). A second example is the combination of adaptation and backward masking. If so-called forward masking from one sound burst shifts the threshold of a subsequent probe by 10 dB, and if backward masking alone also shifts it by 10 dB, then when the probe is sandwiched between the "maskers", the threshold will be shifted by 20 dB, as Pollack (1964) showed long ago, because forward masking occurs at the cochlea, while backward masking occurs centrally.

Additivity of effectivenesses of agents that operate at the same place is illustrated when two different noises are producing TTS. If noise A alone produces 10 dB of TTS and noise B also would produce a 10-dB TTS at the same test frequency, then additivity of effectiveness would predict that the combined effect should be a TTS that would result from doubling one or the other dose, which will always be less than the 20 dB that would be expected if action occurs at different sites. (Note that the combined effect will not necessarily be 13 dB, as the "addition of powers" principle of Humes and Jesteadt (1991) would predict.)

An interesting experiment whose results are interpretable if the foregoing principle is applied was recently reported by Mills (1992). Two groups of gerbils were exposed consecutively to two noises. Group I was exposed monaurally to a 3.5-kHz pure tone T at 113 dB SPL for 1 h; 6 weeks later the permanent threshold shift was measured (PTS_T) and the animals were then exposed binaurally to a wide-band noise N at 95 dBA for 2 weeks, after which PTS_{T+N} was determined. Group II was exposed in the reverse order, so that PTS_N and PTS_{N+T} were measured. PTS_{N+T} was approximately equal to $PTS_N + PTS_T$, e.g. at 4 kHz, PTS_N was 26 dB, PTS_T was 20 dB, and PTS_{N+T} was 43 dB, thus implying that the two noises acted at different places. However, PTS_{T+N} was much smaller than P_{N+T}; at 4 kHz, it was only 30 dB (about 10 dB more than PTS_T). A reasonable interpretation of these facts is that the 113-dB tone not only produced some damage to the cochlea but also to the middle ear, damage that resulted in less sound reaching the cochlea when the 85-dBA noise was subsequently presented. The key clue in this case was the additivity of effect in at least one of the two orders.

The foregoing experiment also illustrates the fact that simple addition of effect or addition of effectiveness is not the only possible outcome of interaction experiments. A second example of this is the outcome of an experiment designed to determine the combined effect of steady noise and impulse noise (Ward, 1988). A 20-min exposure to a 2-kHz octave band of noise at 90 dB SPL generated a 13.4-dB TTS_2 at 2.8, 4 and 5.6 kHz. A 20-min expsoure to 136-dB-peak impulses delivered at 4/sec developed a TTS_2 of 10.1 dB. The combination

(simultaneous presentation), however, only produced a TTS_2 of 12.0 dB, not only far less than the sum of effects (23.5 dB), but even less than the sum of the effectivenesses, again presumably because of the action of the middle-ear muscles. A similar result was obtained by Ahroon et al. (1988, 1993), who studied the combined effect of steady and impact noises in the chinchilla.

Is it possible to separate out the contribution to a given HTL by industrial noise from the contribution by sociacusis, nosoacusis and presbyacusis, as ISO 1999 attempts to do? If the sociacusis, nosoacusis and presbyacusis always acted at a locus (or loci) different from where industrial noise has its effect, there would be no problem, as the additivity principle would apply: the NIPTS would be expected to be the difference between the HTL and the "age correction". Indeed, this is the assumption almost universally accepted. However, although an effect due to aging alone--true presbyacusis--might well occur at all parts of the auditory chain, and so be expected to be additive, the effect of sociacusic influences--the noises of everyday life--must be assumed to act at the cochlea, just as the industrial noise does. Nosoacusis, representing the effect of all noxes except noise and aging, would obviously act at different loci depending on its nature.

It is therefore somewhat surprising that, at least until the expected loss of sensitivity exceeds 60 to 70 dB, the "age effect" (a combination of P, S and N) does appear to be additive with INIPTS, as ISO 1999 assumes. Macrae (1991), for example, found that the change in threshold over a period of 10 years of some Australian war veterans was the same for men with preexisting losses as in those with hearing in the range of normal--i.e., the "age effect" is independent of initial threshold. This success of invoking additivity of effect in dealing with "age correction" could mean that most of the age effect is due to nosoacusis and presbyacusis, with little contributed by sociacusis, if sociacusis indeed acts on the same cochlear structures as industrial noise. A curious state of affairs, surely.

To return to the question of to what H_0 one should add the age correction, whatever its basis, Buren et al. (1992) tested 10-, 14-, and 18-year-old Norwegian youngsters using ISO standard 8253-1, excluding conductive losses, and found that at all ages the average HTLs were not zero, but 2-3 dB through 3 kHz, 4 dB at 4 kHz, 6 dB at 6 kHz and 7.5 dB at 8 kHz. These values are quite similar to those proposed by Robinson (1988). The epic study of a random sample of the British population (Davis, 1992) unfortunately did not report thresholds of 18-20-year-olds separately; however, the median of 18-30-year-old males with no history of workplace noise exposure and no air-bone gaps (hence no marked conductive loss) was 6, 3.5, 4, 6.5, 8.5, 15 and 9.5 dB at .5, 1, 2, 3, 4, 6 and 8 kHz respectively. Even granting that some some sociacusis and nosoacusis is contaminating the data because of the extra decade of living, it is clear that audiometric zero is not representative of young people as they enter the work force. Finally, in a study of 60-year-old Swedish men (Rudin et al., 1988), the mean differences between the observed HTL and the age correction of Spoor (and of ISO) in men with "no noise exposure" and normal tympanic membrane, were 4, 3, 1, 2, 2, 5 and 12 dB, values not far different from the "audiometric zero" correction of Buren et al.

The fact of the matter is that H_0, the assumed HTL of 18-year-olds as they enter the work force, is not any fixed quantity at all. It will be different for different audiometric techniques, instructions to the worker being tested, and

definition of threshold, inter alia. The belief, usually mistaken, that it is zero will probably continue to lead to overestimation of hazard of a particular occupation now that ISO 1999 has been reaffirmed.

The Effect of Intermittence

In ignoring the effect of intermittence on NIPTS, ISO 1999 has for computational simplicity abandoned empirical evidence dating back even longer ago than 1969, when Sataloff et al. pointed out that the HTLs of miners who work in intermittent noises of 115-120 dBA were not as high as the equal-energy theory would predict. The data, however, were scanty; a single point such as Sataloff's could not provide a basis for modifying the equal-energy principle. In order to generate such definitive data, our laboratory has conducted over the past 15 years a long series of exposures of chinchillas using various temporal patterns of exposure to a 700-2800-Hz noise. The growth of PTS measured behaviorally using the method of conditioned avoidance and of outer-hair-cell destruction (DOHC) as a function of exposure energy was first determined for single uninterrupted exposures of various durations and levels ranging from 150 days at 82 dB to 0.015 days (22 min) at 120 dB. It turned out that exposures of equal total energy did produce the same NIPTS and DOHC, with one exception (the exposure for 22 min at 120 dB, which produced massive destruction, implying that the critical exposure had been exceeded), and that both grew with energy in a reasonably consistent manner. Fig. 1 shows the median NIPTS (at 2 kHz) and DOHC as a function of energy. The NIPTS grows at a rate of 1.00 dB/dB,

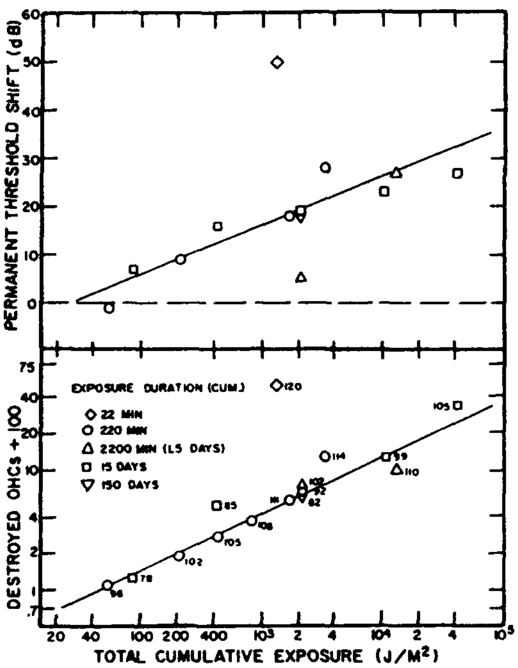

FIG. 1. Relation between auditory damage and exposure severity for single uninterrupted exposures to 700- to 2800-Hz noise in the chinchilla. The top panel shows the median permanent threshold shift at 2 kHz in groups of four animals. The bottom panel indicates the median number of destroyed outer hair cells in the cochleas of seven or eight animals; the number beside each point indicates the SPL of that noise exposure.

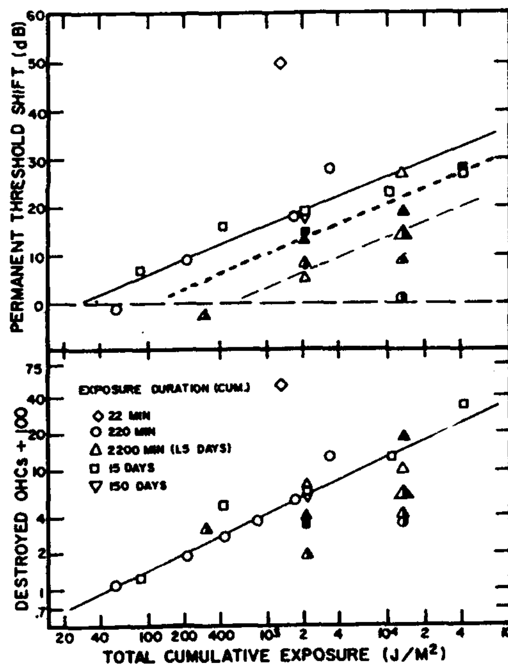

FIG. 2. Effect of interruptions and intermittence on auditory damage from a given cumulative exposure to noise. The open symbols indicate the results for single uninterrupted exposures (as in Fig. 1). Closed symbols represent median results for interrupted exposures in which a given total exposure is broken into 45 daily continuous exposures given Monday through Friday over a period of 9 weeks. The half-closed symbols indicate the median damage when each of those 45 daily exposures is further broken into 40 noise bursts presented once every 12 min or into 10 noise bursts given every 48 min.

beginning at an exposure of 25-30 J/M^2, which, curiously enough, corresponds to the energy in a single 8-h exposure to 90 dB. The DOHC grows at half that rate; i.e., in order to double the DOHC it is necessary to quadruple the energy. Borg and Engstrom (1989) have since shown that the equivalence of total energy for single exposures is true for the rabbit, as the same damage was produced by 30 min at 115 dB or 512 hours at 85 dB of a 2-7-kHz noise. Grenner et al. (1990) also found a growth of PTS with energy of 1 dB/dB in the guinea pig using impact noise. However, when they used a noise whose spectrum was tailored to be the same as the impact noise (Grenner et al., 1989), the growth rate doubled.

With establishment of the validity of the total-energy theory for single uninterrupted exposures, the next step involved determining the effect of breaking up a given dose into the interrupted exposures that characterize the typical work schedule of the developed countries--a daily exposure for not more than 8 h/day on Monday through Friday. A 15-day exposure at 92 dB became 8 h/day for 45 days (9 5-day weeks), and 1.5-day exposures at 102 and 110 dB were each spread out to 9 weeks at 48 min/day. These results are shown by the solid points in Fig. 2, and indicate that the equal-energy principle holds for single uninterrupted daily exposures, even though the damage was not quite as great as when the exposure was continuous.

Thus the groundwork for the final step was laid: replacing 48-min daily exposures by 40 1.2-min bursts delivered at 12-min intervals, for levels of 94, 102 and 110 dB. This pattern of intermittence, with an on-fraction R of 0.1 was known to provide a maximum reduction in TTS. The small half-filled triangles in Fig. 2 indicate the results. The larger triangle represents the PTS from exposures involving 10 4.8-min noise bursts at 110 dB, delivered either every 48 min (and hence spread over the normal 8-h workday) or every 12 (the daily exposure therefore being completed after 2 h), which gave identical results. Since burst duration was clearly more important than the duration of the intervening quiet interval, another exposure was given in which the 40 bursts had a duration of 0.12 min (7.2 sec) but an SPL of 120 dB; the half-filled circle shows that this reduced the median PTS to zero.

The relationship of greatest interest from a practical point of view is that between the interrupted and the interrupted-plus-intermittent conditions. If one fits lines to those data that have the same slope as the continuous exposure (1 dB/dB, it can be seen that the reduction in damage attributable to intermittence represents nearly a 10-dB reduction in effectiveness of the daily exposure energy. The reduction can also be interpreted as meaning that all of the PTS occurs during the first week of exposure (1/9 of the energy is about 10 dB).. To test this heretical notion, a group of animals was given a 9-week exposure to a daily 8-h noise at 105 dB, but with a week of recovery inserted after the first week of exposure in order to measure PTS, and again after the fourth week, as well as at the end of the experiment. The PTS was exactly the same after the first week as after the ninth, so the notion that most of the damage to whatever mechanism is responsible for PTS occurs in the first few weeks of exposure even in man is still viable.

Campo and Lataye (1992) have recently reported a similar study but using the guinea pig, a 1/3-octave band of noise at 8 kHz, and 14 consecutive days of exposure. In this case, the growth of PTS (using compound action potential as the indicator of auditory sensitivity) with energy is much steeper than for

the chinchilla (3 dB/dB) and the reduction in effectiveness produced by changing a 240- or 48-min exposure to a series of 2-min bursts is only equivalent to about a 2-dB reduction in exposure energy.

It is difficult to explain the apparent huge difference between the chinchilla and the guinea pig, especially since Fredelius and Wersäll (1992) showed that merely inserting a 1-h period of quiet between two 3-h exposures to a 3850-Hz tone at 108, 114 or 120 dB SPL reduced hair cell damage in their guinea pigs by 30 to 50 percent.

However, if the chinchilla is more similar than the guinea pig to man, adopting the equal-energy rule to assess all patterns of exposure (ISO has gone so far as to define the term "exposure" as only the total A-weighted energy of the daily dose, so that one can no longer use the term in a general sense to denote some other integral of $I^x t$) is vastly overprotective. It is to be hoped that at the very least a simple correction factor based on the degree of intermittence can eventually be worked out.

Susceptibility

Numerous studies continue to attempt to determine the factors that combine to produce individual differences in susceptibility to otologic hazards, especially noise damage.

Outer ear. Rodriguez and Gerhardt (1991) determined the resonant frequency of the ear by comparing sound pressures at the entrance to the ear canal and at the eardrum, and showed that the higher the resonant frequency, the higher the frequency of maximum TTS from exposure to a broadband noise. There was, however, no relation between the resonant frequency and magnitude of TTS.

Middle ear. Presumably any anomaly of the middle ear that affects sound transmission must have an effect. Avan et al. (1992) studied the effect of the acoustic reflex on the CM of the guinea pig and the rabbit, finding that although the guinea pig's reflex was capable of reducing the CM at 400 Hz by 15 dB, it did not do so in response to a high-intensity contralateral acoustic stimulus in two-thirds of the animals tested. Results in the rat by van den Berge et al. (1990) are more like what is inferred to take place in man: activation of the reflex reduced the CM at all frequencies, including a reduction of 8 dB at 2 kHz.

Right-left disparity. The average left ear (LE) has been known to have a slightly higher HTL than the right (RE). Gros et al. (1987) found only a 1-dB difference at 3, 4 and 6 kHz in an analysis of 61,768 audiograms. A similar result was found by Pirilä et al. (1991b), who compared 211 right-handed and 211 left-handed shooters in a random sample of the citizens of Oulu in the expectation that the right-handed shooters would show more loss in the LE, left-handed men more in the RE. In both of these studies, however, the RE was tested first unless the listener indicated that the LE was "subjectively better". This procedure would tend to reduce the RE-LE difference if any "learning effect" is present. Pirilä et al. (1992) confirmed the small differences between ears in young people; they found, however, that in adults when a difference of 30 dB existed, the LE was much more likely to have the loss. In another of the articles derived from the Oulo sample, Pirilä at al (1991a)

got slightly more TTS in the LE than in the RE when the listeners were exposed to a noise for up to 8 hours using earphones.

Resting threshold. The correlation between resting threshold and TTS in the foregoing experiment was about -0.5, in agreement with classical results: the higher the threshold, the lower the TTS (the "less to lose" principle). The implication of this is, of course, that the damaged ear is less susceptible to further damage if all decibels are equal. The same conclusion was reached by Swoboda and Welleschik (1991), who studied 80 persons from the AUVA data base whose hearing had been followed for at least 10 years and who already had a significant loss when first tested. The increase in HTL was small, but was slightly greater in the initially-better ear.

Age. Whether or not the aged ear is more susceptible than a young ear, other things being equal, can be answered only if the answer is "yes". If a comparison were made between the TTS caused by a given exposure in young adults (Y) and in septuagenarians (O) matched to Y in resting threshold, then only the outcome $TTS_O > TTS_Y$ would provide an unequivocal answer. ; If instead the result were $TTS_Y > TTS_O$, it could be because the Os were less susceptible than average or they would not have retained normal hearing for 70 years. Sensibly enough, no one seems to have attacked the question of age and susceptibility in the past five years.

Gender. Mass surveys almost always show that women have lower HTLs than men above 2 kHz, which has often been interpreted as meaning that women have tougher ears than men, statistically speaking. That the difference may more likely be due to differences in noise exposure was shown by Müller and Richartz (1989), who compared the hearing in men and women, taking care to match the groups in immission as well as age. They found that the difference in HTLs almost disappeared. So hiring women for noisy jobs in hopes of reducing NIPTS is probably wasted effort.

Melanin. An unpublished analysis of audiometric data from the 1972-75 PHS survey found that only at 4 kHz was there a significant difference between black and white males (Singer et al., 1980). A comparison of PTS in old albino and pigmented mice (Conlee et al., 1988) produced by 45 min at 126 dB proved nothing about the role of melanin in susceptibility, because although the albinos showed the most PTS, they had resting thresholds that were 20-30 dB better than the pigmented mice. The only evidence in the last 5 years that tends to support a relation between melanin and susceptibility is provided by Barrenäs and Lindgren (1990), who found less TTS following 10 min at 105 dB of 2-kHz 3rd-octave noise in Swedish persons with dark skin pigmentation than with light pigmentation. However, no mention is made of resting thresholds, so this may be merely another instance of "the less to lose, the less the loss".

Vulnerability

Susceptibility depends on relatively fixed characteristics of the auditory system. Vulnerability, in contrast, refers to differences in the effect of noise that depend on factors that may vary in time in the same individual. Studies of vulnerability are basically investigations into the interaction of various agents with noise in producing PTS or TTS.

The past 5 years have seen no work on some conditions, substances, or activities that had seen considerable study heretofore, such as blood cholesterol level, history of smoking, attitude toward the sound (less effect if liked), vitamins, and paint solvents. There is no dearth of replacements, however. So far nobody seems to have tried to link noise exposure to cancer or Alzheimer's disease, but the list of things that have never been studied gets shorter and shorter every year.

The agents studied in the laboratory that were expected to increase NIPTS include cisplatin, salicylate, toluene, iron deficiency, magnesium deficiency, vibration, and exercise. In the case of cisplatin (Gratton et al., 1991), there was a clear synergism (PTS greater for the combination than the sum of the individual PTSs). PTSs from toluene (Johnson et al., 1988) added to NIPTS, indicating a different locus of action of the toluene. However, some of the other agents did increase the PTS resulting from a noise even though alone they produced no PTS. A couple of field studies involving exposure to carbon disulphide (Morata, 1989) and lead in the blood (Schwartz and Otto, 1991) indicated a slightly higher HTL associated with both; the differences,however, were not large enough to be important even when they were statistically significantly different from chance due to a large N. Studies of the effect of exercise failed to confirm an earlier report that exercise increased vulnerability.

On the other side of the coin, there has still been no discovery of a magic elixir that will protect the ear by reducing vulnerability or enhancing recovery. Although carbogen (95% oxygen, 5% carbon monoxide) has been shown to be slightly ameliorative, Hatch et al. (1991) found that 100% oxygen actually had more effect than carbogen when breathed during noise exposure (guinea pigs). Probst et al. (1992), in an elegant double-blind experiment on German soldiers suffering from acoustic trauma or sudden deafness, showed that dextran and pentoxyfilline were ineffective, a placebo producing just as much recovery as the drugs.

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THE ACOUSTIC REFLEX FEATURES AND NOISE DAMAGE TO THE EAR

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SUMMARY

In human subjects with unilateral stapedius muscle paralysis (in Bell's palsy) a significantly larger temporary threshold shift (TTS) was found upon exposure with impulse noise at a repetition rate of 3/s in the affected than in the non-affected ear. For low repetition rate (1/s), where the reflex relaxes between impulses, there was no difference between affected and unaffected ears. In experiments in rabbits it was found that there was also a smaller permanent threshold shift (PTS) when the reflex was activated by a background noise during impulse exposure. In rabbits it was also found that a certain noise dose given as a high-level short-term exposure or a low-level long-term exposure gave different inner-ear pathology and affected acoustic reflex (AR) and auditory brainstem response (ABR) thresholds differently. The high-level short-term exposure gave primarily inner-hair cell (IHC) damage and a substantial elevation of AR threshold. Low-level long-term exposure gave more outer-hair cell (OHC) loss and little IHC damage and caused a lowering of AR threshold particularly for low and mid frequencies. It was concluded that the AR significantly protects the ear against impulse-noise exposure provided exposure conditions are such that the reflex is really active. The study of AR thresholds can give an extended information about IHC- and OHC damage after noise.

I. INTRODUCTION

From an evolutionary point of view the design of the ear can be assumed to be optimal for selecting biologically relevant sounds from the environment and disregarding irrelevant environmental signals and self-produced sounds. Improving detection of faint sounds can easily be thought to serve a biological purpose. On the other hand, a strong sound or a very intense sound is of less obvious value to differentiate. Sounds are normally not the exclusive information carriers about near sources. Vision and somatosensation are likely to be informative in these conditions as well. Faint sounds, however, may be the only signal for an environmental event in darkness or outside the reach of the cutaneous senses.

There is a basic difficulty in the design of the sensory organ in combining high resolution and large dynamic range, particularly if cost aspects are also included - which they certainly are in nature. Therefore, most sensory systems are designed to maximize both parameters. The eye, for instance, has high resolution in the fovea covering only a small part of the visual field, but in combination with a high sensitivity for detection of events in the peripheral vision, and a quick and precise muscular system allows a very good combination of resolution and dynamic range, but at the cost of some time lag. The ear and the auditory system also has features to improve both resolution and dynamic range. The most well studied are the middle-ear muscles which extend the dynamic range by at least 20 dB and, in addition, fulfill another primary purpose of suppressing the influence of self-produced sounds on the auditory organ by decreasing upward spread of masking. Disregarding

speculations of the evolutionary late appearance of strong sounds in industry it is sufficient to mention the high levels of self-produced sounds in man and animals well exceeding 115-120 dB SPL in the vicinity of the head. The question is not whether the middle-ear muscles of the ear were "designed" to protect the ear, but rather how do they influence the function of the ear in the modern industrialized environment of the Western man. Part of this presentation will deal with these aspects.

The problem for the person damaged by heavy noise exposure is the difficulty/inability to follow conversation and perceive socially relevant sounds. Due to technical reasons these problems are usually described in a poorly valid way, as the threshold for pure tones - the audiogram. Obviously, it is important to describe the damage in as many ways as possible - both socially valid ways and with methods giving an extended description of the biological lesion to the inner ear.

II. AIMS

The purpose of this presentation is to illustrate some findings on the protection of the ear provided by the AR during impulse-noise exposure and to introduce some observations on the AR responses in animals with different types of permanent noise-induced hearing loss.

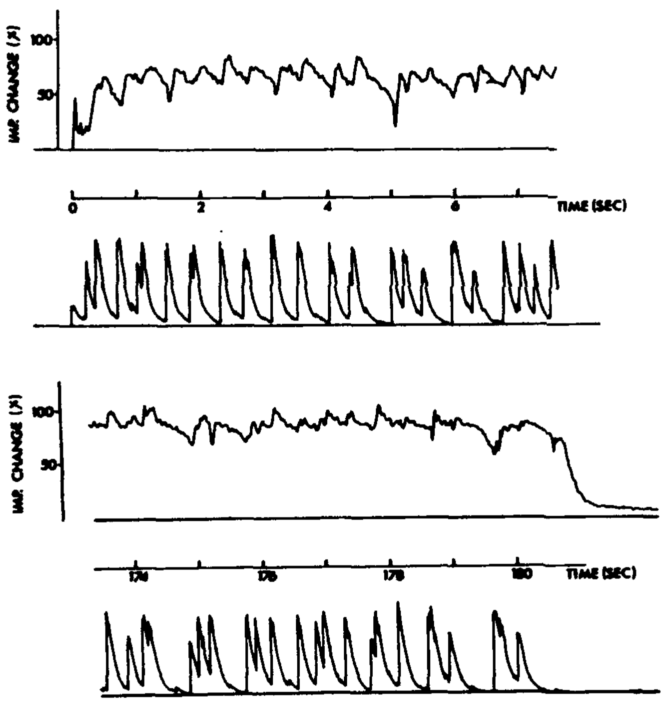


Fig. 1.
Contralateral impedance change in one subject at start *(upper rows)* and the end *(lower rows)* of a 3 min stimulation with 3 impulses/s.

III. PROJECTS

A. Protection provided by the acoustic reflex in impulse noise

Two series of experiments were performed: 1) temporary threshold shift after impulse exposure with different repetition rates was measured in human subjects with normally functioning AR and with stapedius muscle paralysis in Bell's palsy; 2) temporary and permanent threshold shifts were measured in awake rabbits with or without a contralateral reflex activating sound.

1) Human studies

The studies were performed on eight subjects with stapedius muscle paralysis in one ear (Bell's palsy) and normal AR in the other ear. Fig. 1 shows the impedance change in the nonaffected ear upon stimulation with tape-recorded impulse noise (hand sledges recorded from a ship-building yard) obtained at mean repetition of about 3 impulses/s with contralateral stimulation. The peak amplitude was 130 dB SPL. There is a gradual build up of AR keeping a steady level to the end of the stimulation (after 3 min). With a repetition rate of 1 impulse/s the AR response after each impulse had nearly completely terminated before the occurrence of the following impulse (Fig. 2).

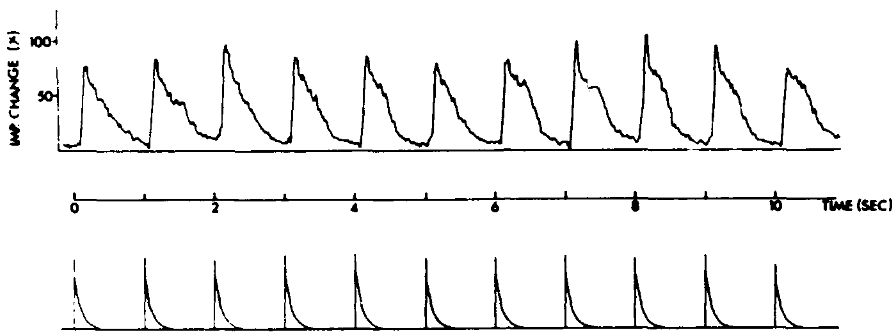


Fig. 2.
Contralateral impedance change *(upper row)* in one subject upon stimulation with 1 impulse/s *(lower row)*

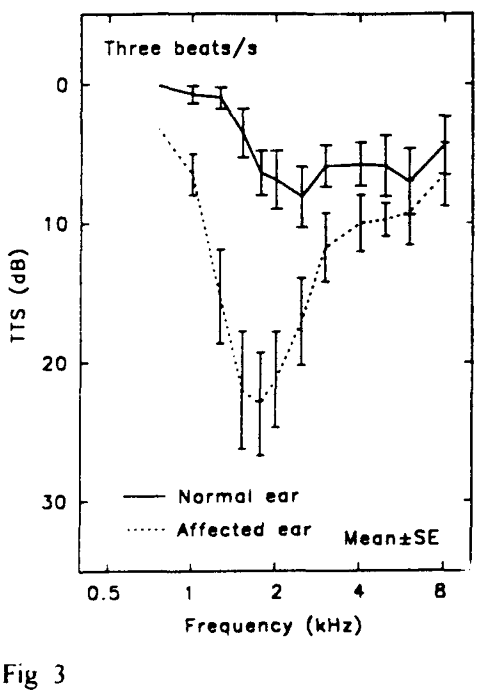


Fig 3
Mean values and standard error of TTS for the affected and nonaffected ear in subjects with unilateral stapedius muscle paralysis after exposure with 3 impulses/s.

In another session the subjects were exposed to the same impulse noise and the TTS was meassured 20 s after the end of the exposure. Fig. 3 shows the mean TTS with 3 beats/s in the ear with the paralyzed stapedius muscle compared with the normal ear. It is seen that the mean TTS shifted towards lower frequencies and was broader and larger compared with the small TTS of the normal ear. With 1 impulse/s there was little or no difference between the ears (Fig. 4).

The experiments indicate that the AR protects the human ear from TTS and, thus, probably also from damage during impulse-noise exposure provided the AR is active during the occurrence of the impulse.

2) Animal experiments

In studies by Counter et al. (1990) it has been shown that the extremely short impulse generated by magnetic coil stimulators used in a clinical testing of central and peripheral neural pathways reach high peak levels (exceeding 140 dB SPL) and exert serious damage to animal ears. The harmful effect on the human ear has not been proved directly, but great caution is recommended, i.e. ear plugs, at the use of this equipment.

The possible protective role of the AR in the damaging processes was investigated in 24 rabbits. Since the repetition rate of the exposure system could not be increased to values giving fusion of the AR response, a different method was chosen to obtain a reflex activity during the impulse: introduction of a contralateral reflex activating 0.1-4.0 kHz noise band. In the first series of experiments it was ascertained that the reflex-activating sound really produced a substantial and stable response in the ear planned to be exposed to the impulse noise. In accordance with our earlier observations this was easily obtained at 20 dB above the animal's AR threshold. No TTS or PTS was seen after the protective sound itself in either ear.

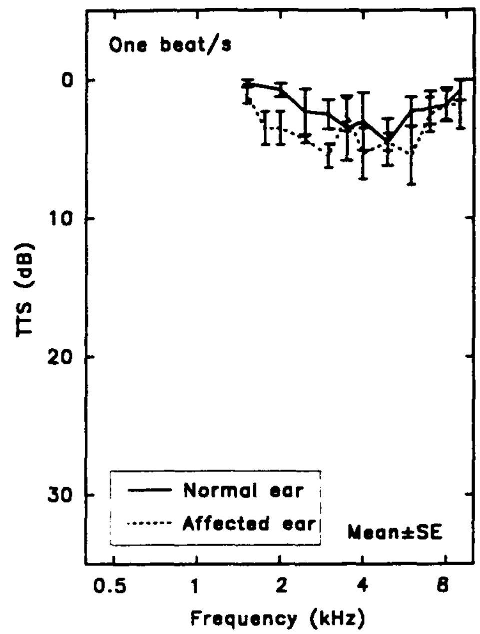


Fig. 4.
Mean values and standard error of TTS for the affected and nonaffected ear in subjects with unilateral stapedius muscle paralysis after exposure with 1 impulse/s.

In a second series of experiments, 50 impulses were presented to one ear during a contralateral reflex activating noise in the other ear. Fig. 5 shows permanent shift of frequency specific ABR thresholds three weeks after exposure with *(above)* and without *(below)* protective sound. A dramatic difference between the two conditions is seen. In this series of experiments we did not cut the middle-ear muscles to show that the protection was exclusively due to the AR action, but in a similar earlier experiment with continuous sound we found closely the same effect if the animals were anaesthetized or if the stapedius muscle was cut indicating that most of the protection was excerted by the AR (Borg et al., 1983).

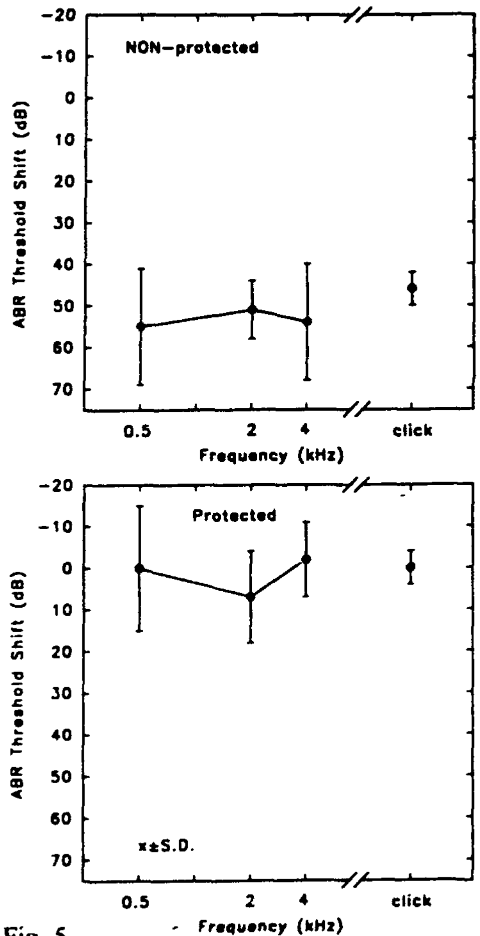


Fig. 5.
Mean (±SE) permanent ABR threshold shift in rabbits exposed to 50 high-level impulses without *(above)* and with *(below)* a conralateral protective 0.1-4.0 kHz noise band 20 dB above AR threshold.

3) Conclusion

The AR has the capacity both in man and animals to protect the ear under impulse-exposure conditions when the AR is really activated.

B. Shift of AR threshold and ABR threshold in PTS

1) Animal experiments

The experiments were performed in rabbits exposed either to a short-duration high-level continuous noise producing a widespread IHC-stereocilia damage or long-term low-level sound (of the same total energy) producing little IHC damage and more OHC loss (Borg and Engström -89). The auditory thresholds were obtained with frequency-specific ABR and the ears were examined in scanning-electron microscope (SEM). Fig. 6 shows two cochleograms based on scanning-electron microscopic analysis, from an animal exposed at 115 dB for 30 min *(above)* and from an animal exposed for 512 h at 85 dB *(below)*. The difference in pattern of IHC and OHC damage is indicated, as well as the differences in audiograms although the exposure spectra were very similar. In a number of animals, AR and ABR thresholds were obtained before and after exposure in the same rabbits. In some cases the post-exposure AR thresholds were compared to the threshold of a normal material (Counter et al., 1989). Fig. 7 shows the shift of ABR and AR thresholds of animals exposed at high-level for short duration *(left)* and animals exposed at low-level at long duration *(right)*. The different shape of the ABR threshold shift is illustrated. The total damage is, however, about the same.

There is a dramatic difference in the effect on the AR threshold between the two exposure conditions. The high-level exposure (with much IHC damage) gives a raise of ABR thresholds (Fig. 7, *left)*. Particularly in the frequency range for the raise of ABR threshold there was a raise of AR threshold as well.

ABR and AR threshold shift after the low-level long-term exposure are shown in fig. 7 *(right)*. There is an improvement of AR threshold, particularly for low-frequency sound with very little influence in the high-frequency region. In these cochleas there was little IHC damage, but more OHC loss.

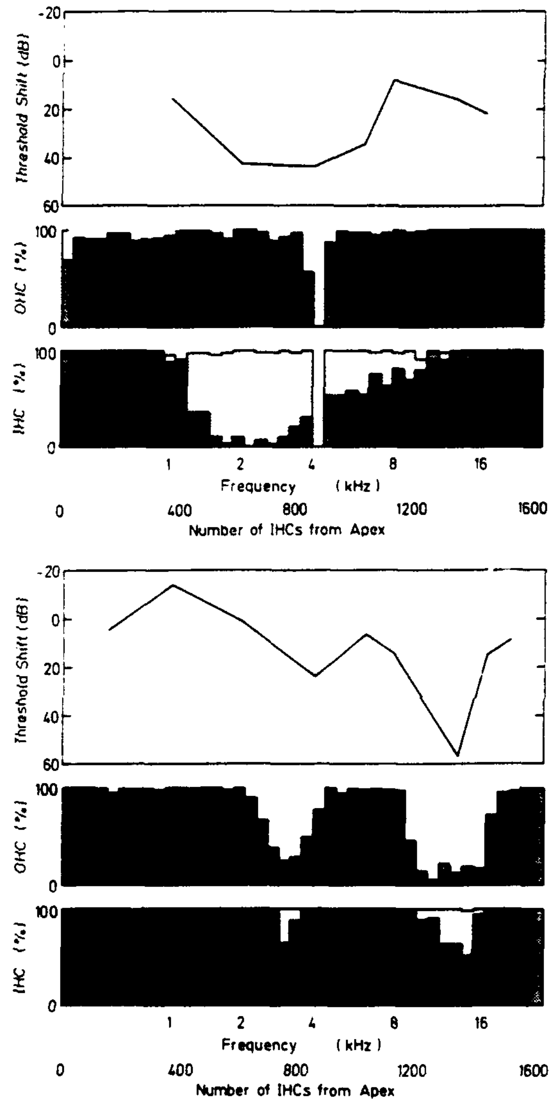
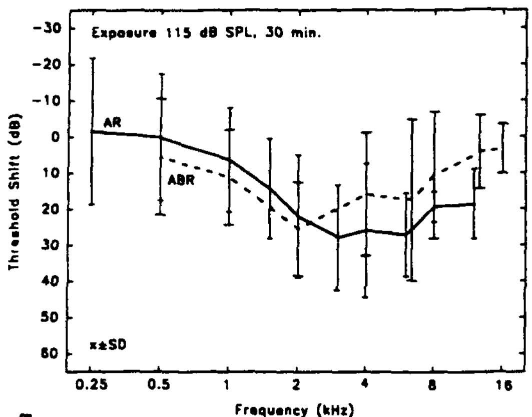


Fig. 6.
Scanning electron microscopic cochleograms from an animal exposed to 115 dB SPL 30 min *(above)* and 85 dB SPL for 512 h *(below)* together with ABR audiograms. Heavily shaded areas indicate present and normal hair cells. Lightly shaded area indicates hair cells with cilia damage (from Borg & Engström, 1989).



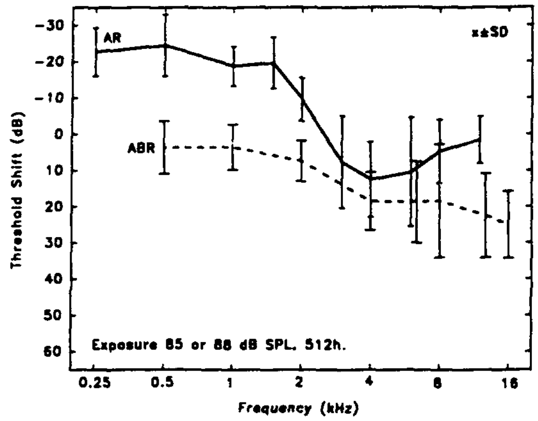


Fig. 7.
Shift of ABR and AR thresholds in rabbits exposed to high-level short-term noise *(left)*. After exposure to low-level long-term noise *(right)*.

2) Conclusion
The ABR threshold and the AR threshold are influenced in a partly different ways in animals having much and little IHC damage, respectively. The combined evaluation for auditory thresholds and AR thresholds may give information about the relative extent of IHC/OHC damage.

IV. DISCUSSION

Single impulses are probably not influenced by the AR since the onset latency of the response is too long. However, the relaxation time may be so long that impulses occurring with less than about one second interval hit the ear when the AR is still active from the previous impulse. Our data strongly support a protective role for the AR under such conditions. The impulse used in the present human study has energy maximum in the 1-2 kHz range and represent a typical ship-building yard impulse/impact noise. Gun shot impulses contain higher frequencies and may partly escape protection in humans. On the other hand, the uninfluenced high-frequency components within such impulses will produce lesions above the frequency range of the speech frequencies (above approx 3 kHz). Thus, they will to a much smaller extent impede the ability to follow conversation and discriminate in socially relevant situations.

The observation of a differential influence of IHC- versus OHC-lesions on the AR threshold in rabbits has so far no counterpart in human studies. Lesions to IHC/OHC on a SEM level have not been compared to AR data in man. The often presented view that noise damages nearly exclusively OHC in human is not necessarily correct. IHC cilia lesions are also common (Engström, 1984). A mixture of IHC and OHC lesions can counteract and give a very little net influence on the AR threshold. A closer study of type of noise exposure, SEM morphology and AR data, is needed.

An interpretation for the different effects on AR thresholds of high-level and low-level exposure can be suggested in terms of frequency-tuning curves (FTCs). Borg et al. (1990) compared AR thresholds of normal and noise-exposed rabbits with FTCs from auditory nerve fibers. They found that the normal AR threshold was closely in the range of the tails of the FTCs. Likewise, in animals exposed to high-level, short-term noise the AR threshold was substantially raised and so were a large proportion of the tails. On the other hand, in long-term, low-level exposed animals with little IHC damage the tails were hypersensitive and the AR threshold lowered. In all three conditions there was a fair, but not complete, correspondence between AR threshold and tails of FTCs.

ACKNOWLEDGEMENT

Work Environmental Fund, project no. 79-0800 and Medical Research Council, project no. 4958

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MODULATION OF AUDITORY SENSITIVITY BY SOUND CONDITIONING

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Protection against noise trauma can be achieved by conditioning animals to a low-level, long term acoustic stimulus prior to a damaging exposure. The activity of the outer hair cells is maintained during sound conditioning and after exposure to the traumatizing noise exposure as determined by the amplitude of the cubic distortion product emission. Morphological analysis has revealed that the outer hair cells are selectively and extensively damaged by the high-intensity noise exposure and sound conditioning significantly reduces the area of damage. Sound conditioning alone does not cause any morphological or functional damage to the cochlea. Moreover, the outer hair cells in sound conditioned ears contain an increased number of vesicles in the presynaptic region. These findings imply that the auditory system can be modulated by sound conditioning. The anatomical site responsible for the effects of sound conditioning are not known and can lie either in the peripheral or central nervous system. The findings presented here provide a foundation on which to further assess and experimentally test the differences between temporary and permanent noise-induced hearing loss. These findings may be pertinent for the prevention of hearing loss for those individuals who are working in noisy environments.

INTRODUCTION

Already at the end of the 19th century the damaging effects of noise exposure began to be tested (Habermann, 1890). Despite over 100 years of experimental research, our understanding of the mechanisms underlying noise trauma, why certain individuals are more sensitive than others, or the means of protecting against noise trauma, is not clearly understood. The concerted role the peripheral and the central auditory pathway play in modifying the sensitivity of the auditory system during noise trauma is not clearly understood and a better understanding of these interactions and underlying mechanisms is needed.

AUDITORY SENSITIVITY CAN BE MODULATED

One of the most intriguing problems in noise research concerns the auditory system's capacity to modulate the adverse effects of acoustic stimulation. An understanding of the auditory system's means of modulating these effects would help elucidate the relationship between a permanent and temporary hearing loss. At present, the underlying physiological, morphological, and biochemical mechanisms that distinguish a temporary from a permanent threshold shift are not known. Unfortunately, there are no physiological or morphological features to indicate when a temporary threshold shift might develop into a permanent lesion. Threshold shifts as large as 80 dB can be completely reversible whereas in other cases an

initial shift of 60 dB can result in as much as a 30 dB permanent loss (Robertson et al. 1980; Cody and Robertson, 1983).

One means of better understanding the relationship between a temporary and a permanent noise induced hearing loss is to experimentally manipulate the sensitivity of the auditory system in such a way as to increase or decrease the effects of noise. For example, the degree of noise-induced hearing loss can be manipulated by increasing or decreasing body temperature (Drescher, 1976; Henry, 1984). These changes are reversible, do not change pre-exposure thresholds, and are believed to be of cochlear origin. Protection from noise trauma can occur also through the activation of the efferent system (Cody and Johnstone, 1982). A protection of the ipsilateral ear occurred when the contralateral ear was simultaneously stimulated at the same frequency but at a lower intensity. This effect was blocked by strychnine, a known blocker of the efferent system in the inner ear. Furthermore, high rates of electrical stimulation of the crossed olivocochlear bundle presented simultaneously with acoustic stimulation reduced the magnitude of a temporary threshold shift (Rajan, 1988).

Another means of reducing the susceptibility of noise trauma is by exposing experimental animals to interrupted noise. Miller et al. (1963) demonstrated that when cats were exposed to interrupted noise the threshold shift declined during the later part of the exposure compared to threshold obtained after the first day. Another interesting study has shown that intermittent exposures resulted in a reduced threshold shift (Clark and Bohne, 1987). In addition, less cochlear damage was found in the group intermittently exposed compared to chinchillas exposed to a continuous exposure of equal energy (Clark et al. 1987).

Finally, activation of the middle ear muscles can also protect against noise trauma. The stapedius reflex is bilateral and is activated at a sound level of approximately 85 dB hearing level in humans, and slightly lower in certain animals. The middle ear muscles are known to adapt rapidly during exposure to high frequency tones, yet are more stable at frequencies below approximately 2 kHz, and in time-varying noise (Borg and Nilsson, 1984). The stapedius muscle has been shown to influence the susceptibility of the ear to permanently induced threshold shifts in experimental animals (Borg and Nilsson, 1984).

It is clear from these observations that the degree of hearing loss induced by noise exposure can be modulated by a variety of experimental manipulations. These findings can provide a foundation for further assessing, and experimentally testing, the differences between temporary and permanent noise-induced hearing losses and how different manipulations can modify these effects. The remaining part of this article will deal with another means of modulating auditory sensitivity to noise trauma. As will be shown, protection against noise trauma can be achieved by conditioning animals to a low-level, long term acoustic stimulus prior to a damaging exposure.

SOUND CONDITIONING: A LOW LEVEL, LONG TERM NON-DAMAGING ACOUSTIC STIMULUS

The sound conditioning experiments originated from current concepts of auditory physiology which include active cellular mechanisms. According to several sequences of deduction, the outer hair cells are believed to be the source of the active cochlear amplifier. Since isolated outer hair cells change their length when stimulated electrically, chemically, and mechanically (Brownell et al. 1984; Zenner, et al. 1985; Ashmore, 1987; Dulon et al.

1990; and Canlon et al. 1988), they are believed to be the structural entity responsible for the active mechanism. In addition, when the crossed olivocochlear efferent fiber system, whose synaptic endings contact directly with the body of the outer hair cell, are stimulated, acoustic emissions are affected directly (Mountain, 1980). A postulated function of the motile response of the outer hair cells is to modify cochlear sensitivity and frequency selectivity. It was then questioned whether or not it may be possible to "train" the outer hair cells, as is done with muscles, with the anticipation that the cochlea would be able to tolerate higher levels of acoustic stimulation.

In an attempt to reduce the damaging effects of noise, guinea pigs were "trained", or "sound conditioned" to a low level, long term acoustic stimulus. The primary goal was to sufficiently stimulate the auditory system without causing neither a temporary nor permanent threshold shift. It had been determined previously with brainstem audiometry that a 1 kHz tone at 105 dB SPL for 72 hours caused a permanent hearing loss between 30 and 50 dB (Canlon et al. 1987). After reducing the intensity of the exposure level to 90 dB SPL for 72 hours no threshold shift could be detected. By maintaining equal energy, the intensity of the exposure was decreased to 81 dB SPL and the duration was increased to 576 hours or 24 days. At the end of the 24 day exposure auditory brainstem thresholds were not significantly different from pre-exposure values (Canlon et al. 1988). It is possible, however, that a threshold shift was induced yet that it either recovered before auditory brainstem thresholds were obtained or that the change was below the limits of sensitivity of the brainstem recording technique. In order to assess if there was any transient deleterious effect of the sound conditioning, the auditory brainstem response and distortion product otoacoustic emission amplitudes were tested at selected frequencies before and during the 24 day exposure. The auditory brainstem response threshold and the distortion product otoacoustic emission (2f1-f2) was obtained before the initiation of the sound conditioning and after 1, 5, 10, 15, and 24 days of exposure to the 1 kHz tone at 81 dB SPL. The auditory brainstem responses did not show a threshold shift at any time during sound conditioning for any of the animals. Variations in the threshold response were no more than 5 dB for all animals and for all the times studied.

The amplitude of the distortion product otoacoustic emission was recorded at the same time intervals as the auditory brainstem responses mentioned above. Distortion product otoacoustic emissions (DPOAEs) are believed to be one type of physiological response of the mechanically active system in the inner ear. While the precise structural site responsible for the generation of the distortion product otoacoustic emissions has not yet been determined, the outer hair cells are presumed to play an important role. For example when the crossed olivocochlear efferent fiber system, whose synaptic endings contact directly with the body of the outer hair cell, are stimulated, acoustic emissions are affected directly (Mountain, 1980).

When stimulating the normal cochlea with two primary tones, f_1 and f_2, the auditory system responds in a nonlinear fashion by generating distortion products. This distortion is converted into acoustic energy which can be recorded with a sensitive microphone placed in the ear canal. The most readily detectable distortion product is the lower cubic difference tone ($2f_1$-f_2). When recorded in the ear canal, the level of the cubic difference tone typically lies 20 to 40 dB below the level of the primaries. The amplitudes of the distortion products are dependent on the frequency relation of the primary tones, but also reflects the morphological integrity at the region where the primaries interact.

The effect of sound conditioning on the amplitude of the distortion product otoacoustic emission (2f1-f2) was tested before the initiation of conditioning and after 1, 5, 10, 15, and 24 days. The response of three different animals is illustrated for two frequencies 2.1 (left) and 1.75 kHz (fig. 1). The open circles represent the pre-sound conditioning values. At each measurement there was an increase in emission level with increasing stimulus level. At approximately 70 dB SPL there was, in some subjects, a decrease by 5 or 10 dB after which the emission grew again with increasing stimulation. Animal 292 showed depressed distortion product amplitudes after one day of sound conditioning and then again at the end of the 24 day stimulus. The depressed emissions were noted at both 2.1 and 1.75 kHz. At present it is not known how rapidly the distortion products regain their original amplitude, but after one week post-sound conditioning, all animals have normal distortion product amplitudes. Animals 293 and 296 maintained normal distortion product amplitudes during the entire course of the sound conditioning.

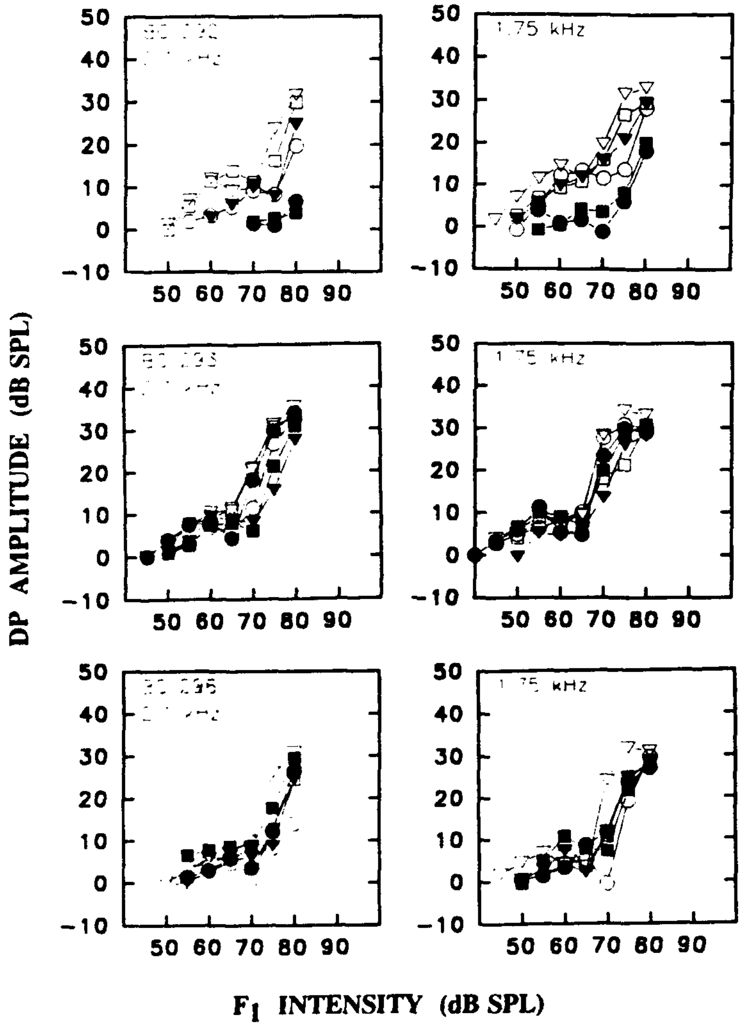

Fig.1. The distortion product otoacoustic emission (2f1-f2) at either 2.1 or 1.75 kHz. Control values (open circles), and at 1 (closed circles), 5 (open triangles), 10 (filled triangles), 15 (open squares), and 24 (filled squares) days of sound conditioning

"SOUND CONDITIONING" PROTECTS OUTER HAIR CELL MORPHOLOGY AND PHYSIOLOGY

Within ninety minutes post-exposure to the traumatic noise (1 kHz, 105 dB SPL, 72 hrs) the auditory brainstem response thresholds for the control group and the sound conditioned group were elevated at all frequencies (0.5, 1.0, 2.0, 4.0, and 8 kHz). The control group showed a 20 to 50 dB threshold shift, whereas the sound conditioned group showed a 10 to 40 dB threshold shift (fig. 2). There is a significant difference between the threshold shift for the two groups. After either a one or two month recovery period, auditory brainstem thresholds improved for both groups. The sound conditioned group showed complete recovery while the control group continued to show a 20 to 30 dB threshold shift.

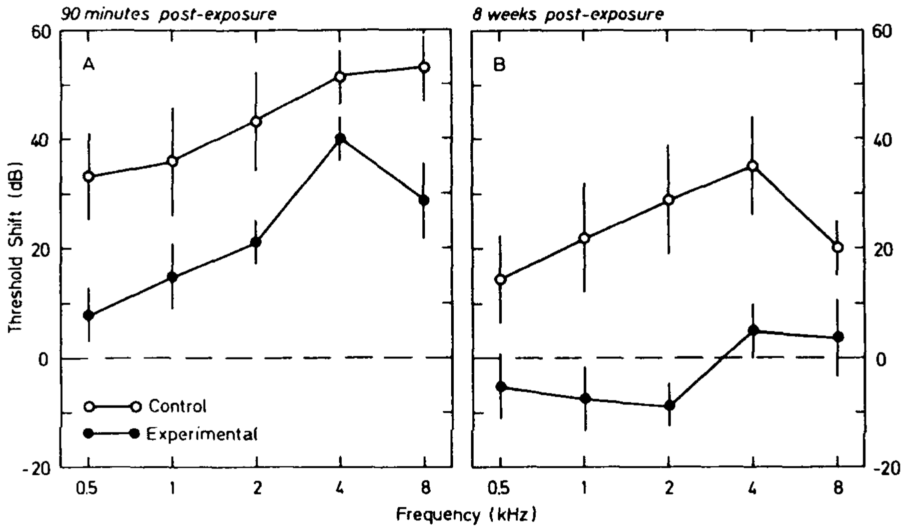

Fig. 2. Protection from noise trauma by sound conditioning. The control group is exposed to 1 kHz, 105 dB SPL, for 72 hours (open circles); the experimental group was sound conditioned with 1 kHz, 81 dB SPL for 24 days prior to the 1 kHz, 105 dB SPL, 72 hour exposure (closed circles).

These findings illustrate how sound conditioning can ameliorate the damaging effects of a second noise exposure that is expected to yield a permanent hearing loss. The underlying mechanisms for the protection against a permanent hearing loss induced by noise trauma is not yet known. Interestingly, these findings are neither particular to the guinea pig nor to the sound conditioning regime, since it has been shown that the rabbit responds to a similar, yet modified, sound conditioning paradigm in the same fashion (Canlon et al., 1991). Slight modifications of the sound conditioning paradigm may be essential for the particular species studied. Recently, protection against noise trauma by sound conditioning has been demonstrated in other laboratory animals (Campo et al., 1991). Most exciting, protection against a temporary noise trauma has been demonstrated recently by sound conditioning humans (Miyakita et al. 1992).

OUTER HAIR CELL FUNCTION AND MORPHOLOGY IS PRESERVED BY SOUND CONDITIONING

FUNCTION

Over the years a number of investigations of otoacoustic emissions have demonstrated that the amplitude of these responses were reduced after noise or drug induced damage. The reduction in emission amplitude has most often been correlated to alterations to the outer hair cells (Brown et al. 1989, Lonsbury-Martin et al. 1991). A distortion product otoacoustic emission "audiogram" can be obtained where distortion product amplitude is plotted against the geometric mean of the primaries ($\sqrt{f_1 * f_2}$). The geometric mean of the primary tones is of importance because it has been shown that the major contributor to the distortion product is generated near this particular site (Brown and Kemp, 1984; Martin et al., 1987). Furthermore, the distortion product emission audiogram is believed to give frequency specific information about the functional status of the inner ear, in particular, the outer hair cells.

At low stimulus levels of f1 and f2, the distortion product emission has been shown to be sensitive to slight alterations in cochlear function. Unlike at higher stimulus levels, the distortion products are insensitive to drastic changes and are even receivable for several hours after death. To determine if sound conditioning has preserved the functional activity of the outer hair cells, distortion product emission audiograms were generated from a control group and a sound conditioned group before exposure to the traumatizing noise (1kHz, 105 dB SPL, 72 hrs) and one month post exposure. In figure 3 the open circles represent the pre-noise values and the closed circles represent the measurements made at one month post exposure to the traumatizing noise. When the intensity of f1 was maintained at 50 dB, the control group (fig. 3A) shows a significant difference (Students t-test, $p<0.05$) between the pre and post measurements obtained at 4, 5, 6.3, and 8 kHz. The sound conditioned group (fig. 3B) does not show a significant difference at any frequency measured. Similar results were obtained when f1 was maintained at 60 dB.

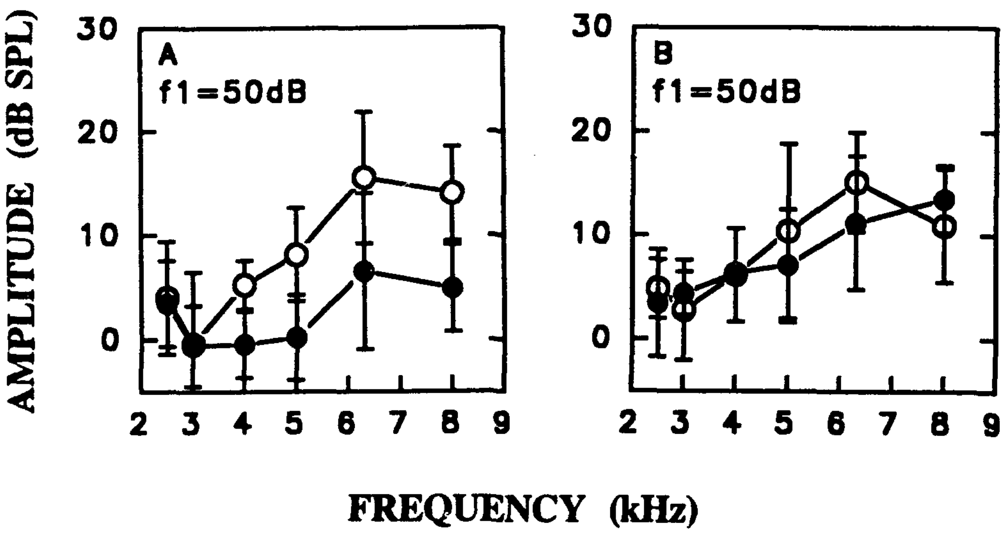

Fig. 3. Distortion product otoacoustic emission audiogram at f1=50 dB SPL measured prior to the traumatizing noise (1 kHz, 105 dB SPL, 72 hrs) (open circles), and one month post exposure (filled circles). (A) control group; (B) sound conditioned group.

These results imply that the outer hair cells do not have the same degree of damage from the traumatizing 'one as the control group. The outer hair cells have been protected through an unknown r⁻⁻.nanism by sound conditioning. These findings however, do not indicate that protection ag. noise trauma incurred by sound conditioning is a direct action of the outer hair cells. A variety of other cochlear and non-cochlear sites or even a combination of sites may be responsible for the protective effect.

MORPHOLOGY

The assessment of cochlear morphology was performed at the light and electron microscopic level. Cochlear surface preparations were stained with fluorescently labelled phalloidin which specifically labels structures containing filamentous actin. Since the apical part of the hair cells contain actin bearing structures, they react specifically with phalloidin. The use of phalloidin has eased the burden of counting the hair cells as well as determining stereocilia and cuticular pathology. Analysis of cochleae from a) sound conditioned; b) noise exposed; and c) sound conditioned and noise exposed animals were analyzed one month after the exposure to the traumatizing 1 kHz tone at 105 dB. Cell counting of cochleae from the group only sound conditioned revealed no hair cell loss. The group exposed only to the high intensity noise exposure showed an 18% loss of first row outer hair cells, a 20% loss of second row outer hair cells and a 20% loss of third row outer hair cells throughout the entire cochlea (fig 4, solid bars). The sound conditioned and noise exposed group showed significantly less outer hair cell loss compared to the noise exposed group. The sound conditioned and noise exposed group showed a 10% loss of the first row outer hair cells and a 9% loss of second row outer hair cells and an 8% loss of third row outer hair cells throughout the entire cochlea.

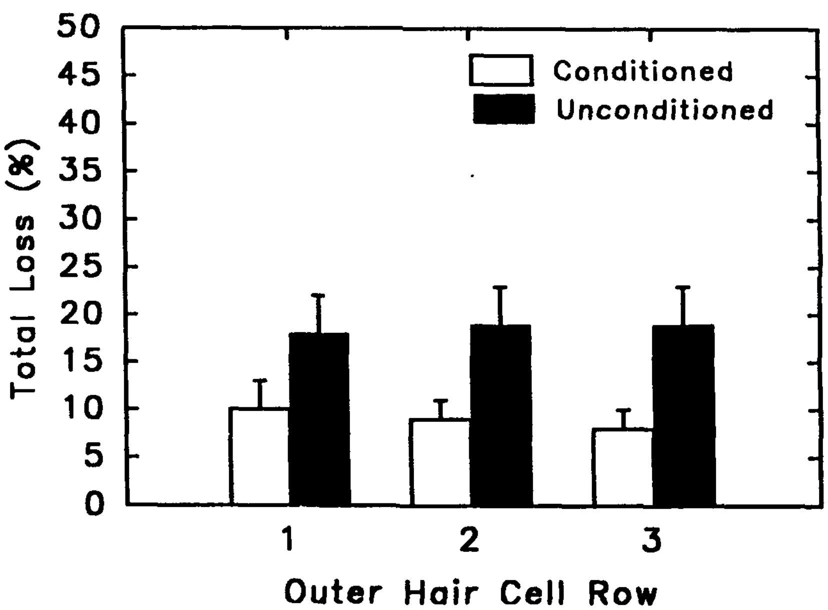

Fig. 4. Cochleogram for the total outer hair cell loss for the sound conditioned group (open bars) and the control group (filled bars).

To determine if the intrinsic properties of the outer hair cells had been modified by the sound conditioning, an electron microscopic investigation was performed (Canlon et al. 1993). Animals were divided into 4 groups: (1) controls, (2) sound conditioned, (3) sound conditioned and exposed to high intensity noise, (4) exposed only to the high intensity noise. No obvious alterations were noted for the stereocilia, cuticular plate, subsurface cisternae or the efferent terminals under the outer hair cells. It was however noted that the number of vesicles opposing the afferent nerve endings of the outer hair cells varied among the different groups. Quantitative morphometric measurements were made from micrographs of the synaptic region at the base of the outer hair cells. The total number of vesicles, coated vesicles, and smooth cisternae were traced directly from the electron micrographs. Only sections that were from the middle part of the cell, showing full profile of the nucleus were studied. The total number of vesicles, coated vesicles and smooth cisternae were corrected for the total number of afferent synapses in each section studied. Figure 5 shows representative tracings from electron micrographs of the base of the outer hair cells from the four different groups.

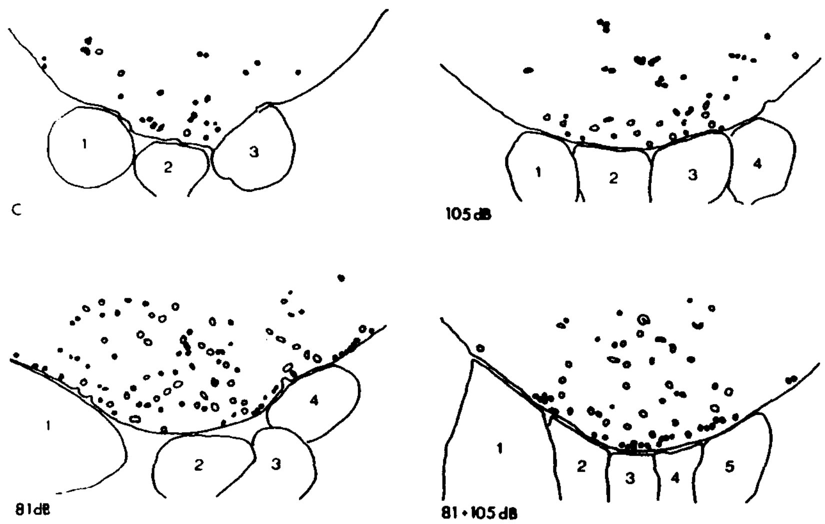

Fig. 5. Tracings from electron micrographs of the base of the outer hair cells from 4 different groups: control (upper left), exposure to the high intensity noise of 1kHz, 105 dB SPL for 72 hrs (upper right); sound conditioned to 1 kHz, 81 dB SPL, 24 days (lower left); sound conditioned followed by exposure to the high intensity noise.

A stimulus related increase in total membrane components (vesicles, smooth cisternae, and coated vesicles) were observed in the presynaptic region at the base of the outer hair cells. Table 1 illustrates the effect of acoustic stimulation on the membrane components in outer hair cells. Compared to control values significant increases in the vesicle content are noted for the sound conditioned group (81 dB). Neither the size nor the morphological character of these vesicles was altered after sound conditioning. The number of coated vesicles or smooth

cisternae were not significantly different from control values. After the combination of sound conditioning and high intensity noise exposure there was a significant increase in the number of vesicles and smooth cisternea compared to control values. In contrast to the sound conditioned group and the group receiving both sound conditioning and high intensity noise exposure, the group exposed only to the high intensity noise showed a slight reduction in the number of vesicles, smooth cisternae and coated vesicles.

EFFECT OF ACOUSTIC STIMULATION ON MEMBRANE

COMPONENTS IN OUTER HAIR CELLS

	Number of Components per afferent synapse (Mean ± S.D.)			
	Control	105 dB	81 dB	81 + 105 dB
Vesicles	9.7 ± 6.5	7.2 ± 2.6	20.5 ± 4 **	15.4 ± 7.5 **
Smooth Cisternae	8.7 ± 2.0	5.0 ± 2.4	11.0 ± 3.7	16.1 ± 5.3 **
Coated Vesicles	3.6 ± 2.3	2.4 ± 1.6	3.8 ± 1.1	3.7 ± 1.9
Total Membrane	19.8 ± 4.6	17.1 ± 7.0	35.7 ± 6.3 **	36.4 ± 6.3 **

** indicates a statistically significant difference at the 0.5% level Student's t-test

These findings show that acoustic stimulation is capable of modulating the vesicle content at the presynaptic region of the outer hair cell. The increased pool of vesicles found after sound conditioning may be one factor underlying the mechanism for protection against noise trauma. One hypothesis could be that the efferent system is inhibiting the activity of the afferent activity from the outer hair cells and as a consequence, there is an inhibition of transmittor release and thus a inhibition of excitotoxicity.

SUMMARY AND CONCLUSIONS

Protection against noise trauma results by sound conditioning animals to a low-level, long-term, non-damaging acoustic stimulus prior to a potentially damaging exposure. Given the observations described in this summary article, it is apparent that the degree of hearing loss induced by noise trauma can be modified by sound conditioning. The anatomical site responsible for these training effects are not known and can lie either in the periphery or the central nervous system. The findings presented here provide a foundation on which to further assess and experimentally test the differences between temporary and permanent noise-induced hearing loss. These results may also be pertinent for the prevention of hearing loss for those individuals who are working in noisy environments.

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PHYSIOLOGICAL CHANGES UNDERLYING THE NOISE INDUCED "TOUGHENING" EFFECT

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INTRODUCTION

The effect of high level acoustic stimulation on the auditory system depends not only on the acoustic parameters of the exposure, but also on the subject's history of noise exposure. The fact that the auditory system can be made more resistant to temporary threshold shift (TTS) (Clark et al., 1987; Subramaniam et al., 1991) and permanent threshold shift (PTS) (Canlon et al., 1988; Campo et al., 1991), raises interesting questions about the physiological changes in the auditory system induced by the prophylactic exposures. One potential change might be an increased operating efficiency of the middle ear muscles (MEMs). Another possibility might be a significant change in the active processes of the cochlea. Both these possibilities are explored in the following experiments.

EXPERIMENT I: Role of middle ear muscles

Several experiments have shown that the interruption of the MEMs exacerbate the deleterious effects of noise exposure (Borg et al., 1983; Zakrisson et al., 1983). The following experiment examined the role of MEM/s in the development of resistance to noise induced hearing loss (NIHL). Specifically, (a) do animals with sectioned MEM/s show decreased TTS with repeated exposures? and (b) does the sectioning of MEM/s influence the protection afforded by the "conditioning" exposures on hearing loss from a subsequent exposure? The operating hypothesis was that if increased resistance to repeated exposures to noise is a reflection of a more effective acoustic reflex, then sectioning the MEM/s should prevent "toughening" during the "conditioning" exposures. Furthermore, the subjects should be more vulnerable or as vulnerable as control animals to PTS from higher level exposures to the same noise.

METHODS

Twenty-one monaural adult chinchillas (650 to 800 gm.) served as subjects. The animals were randomly divided in to three groups. The first group (N=7) served as control subjects exposed only to the higher level (106 dB) noise. The second group (N=9) of animals with intact MEMs received both the "conditioning" as well as the higher level exposures. Animals in the third group (N=5), were subjected to middle ear surgery and received both the exposures. Hearing levels were measured using evoked potential recordings from a chronic electrode in the inferior colliculus. The animals were exposed to an octave band noise (OBN) centered at 0.5 kHz at 95 dB SPL for 6 h/day for 10 days ("conditioning" exposures), allowed to recover for five days and then re-exposed to the same spectrum at 106 dB SPL for 48 hours (see Campo et al., 1991 for details).

Middle Ear Surgery: In three of the five animals in the third group, the right bulla was opened posteriorly and the stapedius was cut at its insertion at the stapes; in the fourth animal, the tensor tympani was also cut using a trans-tympanic approach. In the fifth subject (sham), the middle ear was opened and closed but the MEMs were left intact.

RESULTS

Pre-exposure thresholds: Virtually all pre-exposure thresholds for the experimental animals fell within an S.D.of animals with intact MEMs and was in agreement with previously reported behavioral thresholds (Mills, 1973). This is an essential pre-requisite that ensures that the animals were free of conductive hearing loss.

TS during the "conditioning" exposures: Sectioning the middle ear muscles produced two results (Fig. 1). First, over the first few days of exposure, animals with sectioned MEM/s were generally in the upper range of TTS in animals with intact MEMs. Second, the TTS in the experimental subjects showed less change over the ten days of exposure, thereby increasing the differences between the two groups. The sham operated animal however, showed the same amount reduction in TTS as the animals with intact MEMs. When the TTS in the experimental subjects were compared with those in a normal group exposed to 100 dB in a previous study (Subramaniam et al., 1991), the two groups showed similar TTS as well as small change in TS over the days of exposure (not shown in figure).

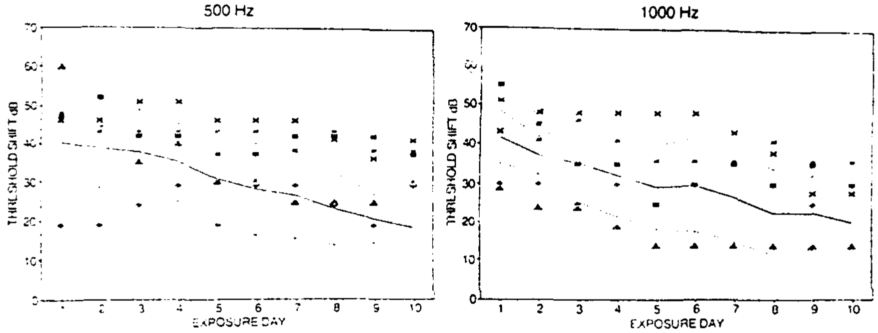

Fig. 1: TTS in the animals with middle ear surgery (symbols) along with the average (solid line) and ± 1 S.D. (dotted lines) TTS seen in animals with intact MEMs.

Permanent Threshold Shift: Four weeks after the last exposure to the 0.5 kHz OBN at 106 dB for 48 hours, PTS was measured. Animals with sectioned MEMs clearly incurred less PTS than the control animals (Fig. 2a). Furthermore, PTS in the animals with middle ear surgery overlapped considerably with those in "conditioned" animals with intact MEMs (Fig. 2b).

DISCUSSION

The sectioning of the middle ear muscles yielded both expected and surprising results. From previous research (Borg et al., 1983), sectioning of the stapes should lead to substantially more hearing loss. There is a clear trend of greater TTS among animals with severed MEMs when compared to animals with intact MEMs. Given the greater amount of TTS, it is surprising that the PTS for the subjects without MEMs is essentially the same as those in "conditioned" animals with intact MEMs. The implication of these findings is that the MEMs are not responsible for increased resistance to PTS and may not ba factor in the "toughening" phenomenon.

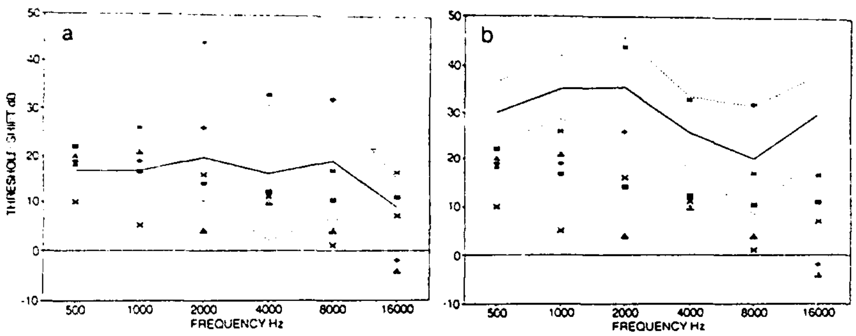

Figure 2. *PTS in subjects with middle ear surgery (symbols) compared with (a) PTS in control animals and (b) PTS in "conditioned" animals with intact MEMs. Solid lines represent the means and dotted lines represent ±1 S.D.*

EXPERIMENT II: Changes in Distortion Product Otoacoustic Emissions

Canlon et al. (1992) reported that there was a proliferation of cellular organelles and presynaptic bodies in the OHCs of guinea pigs following "toughening" exposures. If changes in the OHCs are involved in the "toughening" phenomenon, then these changes might be reflected as alterations in the DPOAE. Experiment II was designed to examine the dynamic changes during and after the "conditioning" exposures, with the goal of learning whether OHC function (as reflected in DPOAE) co-varies with hearing loss during the "conditioning" exposures.

METHODS

Six adult chinchillas served as subjects. Subject treatment, audiometry and noise exposures were essentially the same as in *experiment I.*

DPOAE measurements: DPOAEs were recorded from each animal before, during and after the noise exposure. At least two sets of DPOAE input/output (I/O) functions were recorded prior to the noise exposure over two separate sessions. The average of the pre-exposure measures served as the baseline. DPOAE I/O functions were then recorded at the end of exposures on days 2, 4, 6, 8 and 10. Five days after the final exposure, the animals were tested again.

Test stimuli: All the stimuli were generated and the responses analyzed using a Virtual M 330 system and a Mac IISi computer. DPOAE I/O functions were recorded in 2 dB steps from 30 to 74 dB SPL. The levels of F_1 and F_2 were equal and the F_2/F_1 ratio was 1.2. DPOAE I/O functions were collected at the geometric mean (1, 2, 4 and 8 kHz) of the primary frequencies.

RESULTS

Pre-exposure evoked potential thresholds: The evoked potential thresholds of the six animals were in close agreement with the laboratory norms for normal chinchillas.

Pre-exposure DPOAE I/O functions: DPOAEs clearly above the noise floor could be recorded at all the frequencies tested Fig. 3 (a)-(d).The I/O functions grew almost linearly with slopes of 0.91, 1.13, 1.07 and 1.32 dB/dB at 1, 2, 4 and 8 kHz respectively, when calculated over the entire range of input levels. Some non-monotonicity was noticed at 1 kHz.

Changes during exposure: The changes in DPOAE were frequency dependent as in the case of evoked potential TS (Fig. 3 a-d). At 1 and 2 kHz, DPOAEs decreased significantly by day 2, but recovered to with in 10 dB from baseline by day 10. At 4 kHz, the recovery is less complete. No recovery was seen at 8 kHz. These trends were consistent across the animals.

The changes in DPOAEs were similar to the changes in evoked potentials. TS recorded over the days of exposure showed an average reduction of 20 dB from day 2 to day 10 of exposure at 1 and 2 kHz. There was only a 5 dB reduction in TS at 4 kHz, while TS continued to grow at 8 kHz over the first four days and then stabilized.

Fig. 4 shows the changes seen in one animal over the days of exposure at 1 kHz. DPOAE amplitudes showed a considerable decrease on days 2 and 4 and then recovered to baseline by day 8. Although the DPOAE amplitudes show a complete recovery by day 8, the animal had a TS of 25 dB. Thus DPOAE amplitudes could be normal despite a substantial TS. Such a discrepancy between distortion products and emissions was seen in three of the six animals.

Post-exposure changes: At five days post-exposure, evoked potentials showed complete recovery at all the frequencies. Likewise, DPOAE amplitudes recovered to baseline at all the frequencies (Fig. 6 a-d). At 4 kHz, although within ± 1 S.D., the amplitudes were marginally lower across the levels tested. The same was true of amplitudes at 8 kHz in the mid-intensity range. These reductions in amplitudes are possibly indicative of residual damage at high frequencies.

DISCUSSION

There was a general agreement between the changes in evoked potential thresholds and DPOAEs. Both dependent variables showed maximum depression during the first two days of the exposures. At 1 and 2 kHz, the I/O functions recovered partially over the remaining days of exposure. At the high frequencies (4 and 8 kHz), there is no evidence of recovery either in EVP or in DPOAE measures. There are hints in the data that the DPOAEs actually recover faster than the EVP. If the DPOAE are a reflection of OHC function, then the difference between evoked potential and DPOAE recovery suggests that the OHCs recovered but the IHC/ VIII nerve system was still operating with a deficit (manifested as hearing loss). Using the DPOAE as an index, there is no evidence of change in the OHC subsystem during "toughening".

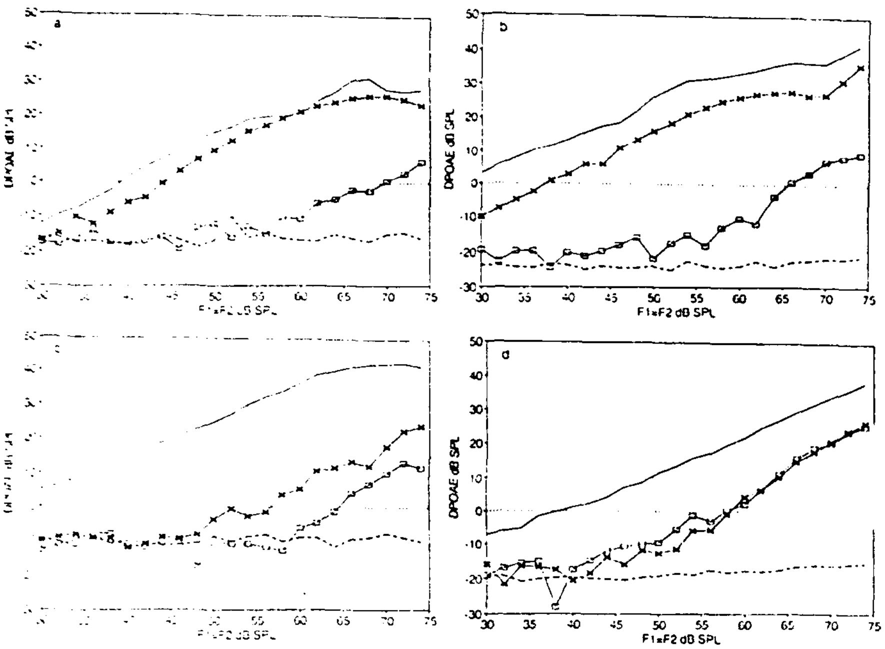

Fig.3. Mean DPOAE I/O functions at (a) 1, (b) 2, (c) 4 and (d) 8 kHz, recorded on days 2 (square) and 10 (cross) of the "conditioning" exposures. Solid line represents the pre-exposure mean. Dotted lines represent the ± 1 S.D. Dashed line represents the average noise floor.

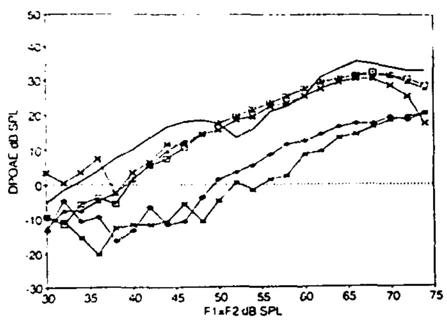

Fig. 4. DPOAE I/O functions recorded before (solid line) and on days 2 (plus), 4 (asterisk), 6 (square), 8 (cross) and 10 (triangle) of the "conditioning" exposure.

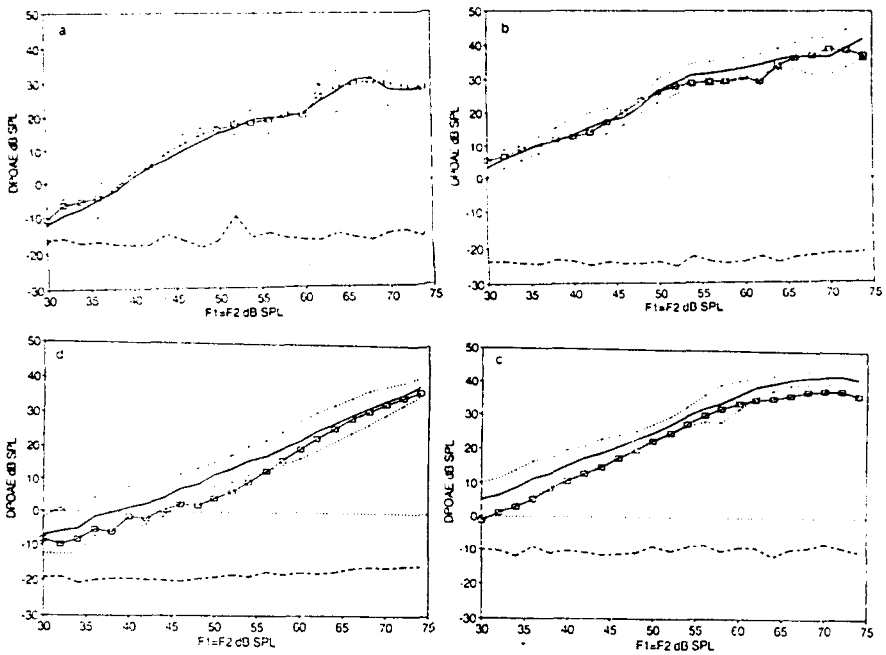

Fig.6. Mean DPOAE I/O functions recorded five days after the last "conditioning" exposure (squares). Solid line represents the pre-exposure mean. Dotted lines represent the ± 1 S.D.. Dashed line shows the average noise floor.

ACKNOWLEDGEMENTS: Work supported by grants from Deafness Research Foundation (M.S.) and NIH 1RO1 DC1237-01A1 (D.H.)

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PROTECTIVE FUNCTIONS OF THE MAMMALIAN OLIVOCOCHLEAR PATHWAYS

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INTRODUCTION.

The ability of the efferent pathways to the cochlea, the olivocochlear bundles (OCBs) originating from the superior olivary complex (SOC) in the ventral brainstem, to reduce the cochlear desensitization caused by loud sound has now been securely established in a number of studies using guinea pigs as the experimental animal (1, 3, 4, 6, 8-10, 12, 13, 16, 18-21, 23, 24; see reviews 14, 15). Despite early reports to the contrary in cats (5, 25), more recent experiments (unpublished results) have confirmed that OCB-mediated protection can also be obtained in this species. Recent experiments in rats (24) have also found OCB-mediated protection from acoustic trauma. These data confirm the generality of OCB-mediated protection in mammals.

The most detailed and systematic studies of the basic protective role of the OCBs have been carried out by Rajan and colleagues. The results have been detailed in previous reports and only the salient features of the observed effects will be summarized here. The reader is referred to the original reports and to reviews of these reports for experimental details and rationales. The studies were carried out in guinea pigs anaesthetized with a barbiturate anaesthetic and paralyzed to eliminate the influence of the middle ear muscles. The animals were tested acutely with a damaging loud sound at a frequency at about the middle of their hearing range and also producing threshold losses over the frequency range of greatest sensitivity of guinea pig hearing measured in audiograms based on the compound action potential (CAP) of the auditory nerve (11, 22). The CAP audiogram was used to establish cochlear sensitivity and to monitor changes in cochlear sensitivity produced by loud sounds. The hearing losses observed in a group of animals subjected to a particular monaural loud sound exposure were compared to the losses in groups of animals subjected to the same exposure combined with a number of other manipulations. The features of protection observed in these experiments, and from the more recent experiments in cats and rats, are summarized below.

FEATURES OF THE PROTECTIVE EFFECTS OF THE OLIVOCOCHLEAR PATHWAYS.

1. Direct activation of the OCBs can reduce the cochlear threshold losses caused by loud sound.

Protection from damage was obtained by direct electrical stimulation of the OCBs either at the floor of the fourth ventricle in the brainstem (9, 10) or at the round window of the cochlea (19, 20). The protection was confirmed to be due to the OCBs since it could be blocked by strychnine injected systemically, with a time course of blocking (9, 19) that paralleled the blocking action exerted by the drug on other cochlear effects elicited by electrical stimulation of the OCBs at the same sites. In the case of electrical stimulation in the brainstem, for which more extensive testing was done, the protection was also shown to be blocked by infusion of an anti-cholinergic drug into the cochlea prior to testing (13). The protection elicited by brainstem stimulation could also be blocked (9) by lesioning the OCB pathways just distal to the brainstem midline site of application of the electrical stimulus.

2. Contralateral cochlear manipulations can elicit OCB-mediated protection through facilitatory influences, without the intercession of any auditory centres higher than the brainstem.

Protection of the loud-sound-exposed test cochlea can also be obtained by manipulations performed at the other (contralateral) cochlea. One of these manipulations is the presentation to the contralateral cochlea of a sound at the same frequency as the ipsilateral exposure, but at a much lower non-damaging level, simultaneous with the ipsilateral exposure (1, 6, 16, 18, 24, unpublished results). The other manipulation is the destruction of the contralateral cochlea just prior to presenting the ipsilateral loud sound exposure (17, 21). The protective effects of each manipulation are blocked by the prior systemic injection of strychnine or by cutting the OCBs in the brainstem midline.

The manipulations at the contralateral cochlea did not produce any changes in a variety of afferent responses or efferent effects at the test cochlea in the absence of the ipsilateral damaging loud sound (1, 16, 18, and see review 15). Thus, the contralateral cochlear manipulations did not directly activate the OCB pathways and produce any overt increase in OCB activity to the ipsilateral cochlea. Rather, they may have resulted in more persistent facilitatory effects at some central site, possibly the cell bodies of the particular OCB efferents involved in protection (see below), allowing them to be more readily activated by the monaural loud sound which could not do so by itself in the barbiturate-

anaesthetized animals. This postulate received strong support from tests showing that lesioning the OCBs in the brainstem midline <u>after</u> destruction of the contralateral cochlea still blocked the protective effects of the contralateral cochlea manipulation (15, 21).

Decerebration at the level of the upper pons, thereby eliminating the influence of descending influences on to the cell bodies of the OCBs in the SOC in the ventral brainstem, did not prevent protection of the test cochlea from a loud sound exposure when contralateral acoustic stimulation was applied (12). Thus, the protective effects of manipulations at the contralateral cochlea appear to be exercised solely through lower brainstem connections to the olivocochlear pathways.

Finally, it has also been reported (8) that a loud monaural exposure, with no other manipulations being performed, can activate OCB-mediated protection. However, this is not a robust effect under all test conditions and has not been seen in other studies (1, 6, 10, 13, 16, 18-21).

3. Protective OCB effects are robust and resistant to deep anaesthesia.

OCB-mediated protection can be elicited with contralateral acoustic stimulation even when other efferent pathways to the auditory periphery are inoperative. Thus, the protection can be elicited by contralateral acoustic stimulation even when it is not possible to elicit any crossed effects through the middle ear muscles (MEM). In a similar vein, OCB-mediated protection can be elicited with contralateral stimulation when other OCB-mediated effects of contralateral sound can not be observed even with detailed testing of a wide variety of cochlear responses in guinea pigs and cats (16, 18, 24, unpublished results). In these cases, the MEM pathways or the other OCB-mediated effects appear to be susceptible to the anaesthetic used and not to survive deep anaesthesia. In the case of other OCB-mediated effects of contralateral stimulation, it is additionally possible that the anaesthetic potentiated inhibitory inputs on those OCB pathways, since these effects are not seen under such anaesthetics, even during periods of decreasing depth of anaesthesia or with light anaesthesia (unpublished results).

4. OCB-mediated protection shows a loss-level dependency and a frequency-dependency.

With all four protective manipulations, no protection was obtained from low-level loud exposures that produced only small threshold losses at the test cochlea (see 14, 15). With higher-level exposures that produced larger threshold losses at the test cochlea, protection was obtained. The amount of protection increased with increasing threshold loss caused by the latter exposures. Across a number of exposures of varying intensity and duration, the amount of protection showed a quasi-sigmoidal relationship to the amount of loss that would otherwise ensue. The a[illegible] of protection saturated at about 17 dB reduction in the threshold losses at the point of maximum [illegible] 4, 15). With electrical stimulation at a higher rate, protection could be obtained even from the low-le[illegible] exposures. Even then, the amount of protection was related to the amount of damage otherwise occurring. A similar loss-level dependence can be seen in a recent study (23) using exposures at intensities ranging from 110-120 dB SPL, but not at 130 dB SPL. However, at this exposure level, hearing loss may also involve structural damage at the cochlea as well as to middle ear structures, and the low amount or absence of protection at this intensity level may reflect the damage of non-cochlear origin.

Protection is elicited more readily at higher frequencies than at intermediate frequencies and is not elicited at all at low frequencies (unpublished results). This result is found when using exposures of equal intensity and duration differing only in the frequency of exposure, where greater threshold losses are found for the high frequency exposures. It is also found to hold true when the more-damaging high-frequency exposures are presented for shorter durations to produce as much threshold loss over the appropriate range of affected frequencies as the longer-duration low-frequency exposures do over the range of frequencies affected by them. This result clarifies the inability of previous studies in the cat (5, 25) to find efferent-mediated protection using low-frequency exposures.

The loss-level dependence also occurs in cats. Mid-frequency, low-level exposures producing small threshold losses did not result in protection, but high-level exposures resulting in large losses did. This is similar to the loss-level dependence in guinea pigs, though the maximum amount of protection gained in the cat was somewhat larger than that in the guinea pig. There also appear to be some species-specific differences in the exact features of the loss-level dependency. Thus, in the cat, at the higher frequencies there is less loss-level dependence than at the mid-frequencies, and strong protection can be obtained even with exposures producing low threshold losses. This result re-inforces the view that OCB-mediated protection is specialized, though not exclusive, to the high frequency end of the cochlea. The latter point is of significance given the great susceptibility of high frequencies to noise-induced damage, as well as to other traumatic manoeuvres.

5. OCB-mediated protection has a "memory" component, exercised at a central site.

With all four protective manipulations, protection could be obtained even when the protective

manipulation was applied some time before the loud sound exposure was presented by itself to the test cochlea. In the case of manipulations with finite periods of application (in this case 1 minute) - i.e., electrical stimulation in the brainstem, electrical stimulation at the round window, or acoustic stimulation at the non-exposed contralateral cochlea - optimal protection was obtained when these manipulations were presented simultaneous with, and for the duration of, the ipsilateral exposure. However, application of these manipulations as much as 5 minutes before the ipsilateral exposure still resulted in protection of the ipsilateral test cochlea (9, 16, 18). The protection obtained with the 5 minute delay was less than that obtained with presentation of the manipulation simultaneous with the ipsilateral exposure, but was significant. With a 10 minute delay between the protective manipulation and the subsequent monaural exposure, no protection was obtained. In the case of the manipulation without a finite period of application (namely, contralateral cochlear destruction), protection was found to remain at a constant level with delays of 2-30 minutes between the manipulation and the ipsilateral exposure (16). With a 1-hour delay, there was less, but still significant, protection. Thus, the "memory" component gradually decreases with time.

The memory component of the protective manipulations did not appear to be exercised through direct activation of the OCBs. Rather, it may have been exercised as a facilitatory influence that allowed the subsequent loud sound to more readily activate the protective OCB pathways (see below) where a monaural loud sound exposure by itself did not do so (16, 18, 21, and see review 15). Such facilitatory effects were shown to be exercised at a central site and not at the test cochlea subsequently exposed to loud sound, in tests in which the OCBs were lesioned in the brainstem midline in the period between first applying either one of two protective manipulations (electrical stimulation in the brainstem, or destruction of the contralateral cochlea) and then presenting the loud sound exposure to the test cochlea. In neither case was protection obtained at the test cochlea (9, 21).

6. Protection can be obtained from higher auditory centres, through facilitatory influences.

Protection can be obtained by electrical stimulation of the inferior colliculus (IC) in the midbrain (13). Such protection could be obtained both when the target cochlea was contralateral to the stimulated IC or when the target cochlea was ipsilateral (13). In the latter case, the amount of protection obtained with IC stimulation at any particular rate is less than that obtained with stimulation at the same rate when the IC was contralateral to the test cochlea. At peak protection with either site of stimulation, stimulation of the IC ipsilateral to the test cochlea results in about half as much protection as obtained with stimulation of the IC contralateral to the test cochlea.

This protection is blocked by intra-cochlear injection of an anti-cholinergic drug. This descending influence is potentially a powerful one since equivalent protection could be obtained at much lower rates of electrical stimulation at the midbrain site than required with direct stimulation of the fibers of the OCBs along their lengths at the floor of the fourth ventricle in the brainstem. The gain with contralateral IC stimulation (measured as the ratio of electrical stimulation rate at the brainstem over that at the IC to obtain equivalent protection) was about 7-8 fold for optimal or near-optimal protection, and IC stimulation rates of 20/sec and 50/sec were as effective as brainstem stimulation rates of 140/sec and 400/sec respectively, at eliciting large protection.

Protection elicited with IC stimulation has a memory component (13) as seen with electrical stimulation of the OCB either at the floor of the fourth ventricle or the round window, and with the contralateral cochlear manipulations. The time course of this memory component is similar to that seen with the other manipulations applied for the same finite period of time, and decays totally with a 10 minute delay between the IC stimulus and the subsequent loud sound exposure.

Protection elicited from the IC is observed without the electrical stimulus producing any other effects at the cochlea (13). Thus electrical stimulation of the IC with parameters that when applied directly to the OCB in the brainstem elicit strong OCB effects on cochlear potentials, does not elicit any effects on cochlear potentials. The memory component of the protection elicited by IC stimulation also does not result in any persistent changes in the cochlea although protection can persist even with a 5 minute delay between the IC stimulus and the subsequent loud sound exposure. Thus, the IC stimulus does not appear to directly activate the protective OCB pathways but may provide a facilitatory influence that allows the loud sound exposure to more readily activate these pathways.

7. Protection is exercised by specific components of the OCBs.

In the case of protection elicited by manipulations performed at the cochlea contralateral to that presented the loud sound, it was possible to confirm that the protection of the test cochlea was mediated by the efferent fibres originating from the SOC nuclei principally by the finding that lesions of the OCBs restricted to the brainstem midline would prevent protection being elicited by

manipulations at the contralateral cochlea. These lesions were placed so as to transect only the crossed OCB pathways originating from the side of the brainstem contralateral to the target cochlea exposed to loud sound). In the guinea pig, this crossed pathway consists almost exclusively of fibres of the medial olivocochlear system (MOCS) originating from the medially- and ventrally-located nuclei of the SOC, suggesting that only these OCB fibres are involved in protection.

The finding of protection from the midbrain site confirms that only the MOCS sub-system of OCB fibres are involved in protection since a number of anatomical studies have shown that the IC projects only to this component of the OCBs and not to the other OCB sub-system, the lateral olivocochlear system (LOCS). The protection obtained with IC stimulation further suggests that the OCB-mediated protection may well be exercised by only one sub-set of the MOCS. In a number of species, including the guinea pig, the projections of the IC to the OCB terminate exclusively or almost exclusively in one of the nuclei of the MOCS, the ventral nucleus of the trapezoid body (VNTB).

The difference between the amount of protection with stimulation of the IC contralateral to the test cochlea as opposed to the ipsilateral IC is also consistent with protective OCB effects being exercised by the MOCS. The IC appears to project only ipsilaterally to the cells of origin of the OCB (26). There are about twice as many MOCS to the contralateral cochlea (the crossed MOCS) as there are to the ipsilateral cochlea (the uncrossed MOCS), and this is consistent with the finding that maximum protection with ipsilateral IC stimulation is about half that with contralateral IC stimulation.

The attribution of the protective effects to the MOCS, which terminate in the cochlea on the outer hair cells, also receives support from the data in a recent study (6) in which the protective effects of contralateral acoustic stimulation were observed on both the CAP and the cochlear microphonic (CM) measured in the ipsilateral ear. Given that the CM is very largely dominated by the OHCs, these data show that the protective effect can be attributed to the efferent terminations on the OHCs, i.e., the MOCS. As noted above, it may well be plausible that only one or some MOCS sub-systems participate in the protective process. These MOCS sub-systems may originate from only one or some of the different nuclei within the MOCS system, although it is well possible that there are differences between different sub-sets of MOCS cells from the same nucleus. The latter speculations, about further specializations within the MOCS system, require more information than is currently available on the cellular properties of and inputs to the MOCS cells.

8. Involvement of two strychnine-sensitive synapses in OCB-mediated protection.

Although strychnine blocks the protective effects of all the manipulations, it does so with different time courses. In the case of the manipulations at the contralateral cochlea, systemic injection of strychnine is able to totally block protection within about 15 minutes. In the case of direct electrical stimulation of the OCBs, either in the brainstem or at the round window, the same or higher dose of strychnine administered via the same systemic route is able to block OCB-mediated protection only when it has also blocked the more classical effects of OCB stimulation on cochlear potentials, with a time course of blocking of greater than about 30 minutes. When testing of electrically-elicited OCB effects on cochlear potentials and of protection is done 15 minutes after systemic injection of a high dose of strychnine, the electrical stimulus is still able to elicit classical effects on cochlear potentials and to elicit protection with full strength. Since the electrical stimulus is applied along the lengths of the OCB fibres, the protective effects (and other cochlear effects) of the electrical stimulus can only be blocked by blocking the MOCS synapses at the cochlea. With intra-peritoneal injection of strychnine, this blocking of the cochlear synapses occurs over a period of 30 minutes or more (9, 17, 19, 24) and only then can the protective effects of electrical stimulation of the OCBs be blocked. In the case of the contralateral cochlear manipulations, protection elicited by these manipulations can be blocked either by blocking the MOCS synapses at the target cochlea or any one of the synapses involved in the transmission of information from the contralateral cochlea to the OCBs neurons involved in protection. Thus, blocking of the relevant synapses in the brain would also block the protective effects of the contralateral cochlea manipulations. Systemically-administered strychnine must act at such a site or sites within 15 minutes, thereby blocking the protective effects of the contralateral cochlear manipulations within this period. This data suggests a differential rate of entry of systemically-injected strychnine into the brain versus the cochlea, or a differential susceptibility of the relevant synapses in the brain versus the efferent synapses in the cochlea. Other studies show that systemic administration of strychnine results in a faster uptake in the brain than in peripheral target tissues (such as the eye). It is not known if there is a differential susceptibility of the central synapses involved in the protective OCB pathways as opposed to the cochlear synapses of these pathways. However, this can only be determined after clarifying the exact route by which information from the

contralateral cochlea provides the input relevant to protection.

In general, these data show that protection involves at least two strychnine-sensitive sites. One of these constitutes the MOCS synapses in the cochlea which exert the cochlear effects leading most immediately to reduced hearing losses (i.e., protection), and these synapses are also blocked by anti-cholinergic agents (13). The other site is the central site (or sites) at which, as noted above, strychnine is hypothesized to act in a shorter period after systemic administration so as to block the protective effects of contralateral manipulations.

9. Cochlear mechanisms involved in OCB-mediated protection.

An insight into the cochlear mechanisms for protection from the damaging loud sound exposure is obtained from the observation that electrically-evoked OCB effects on protection and on other cochlear potentials do not follow the same time course of adaptation of effects with a maintained stimulus. The OCB effects on cochlear potentials reach a peak very quickly (within a few tens to hundreds of milliseconds) after the onset of the OCB electrical stimulus and thereafter either adapt out to a low level or else totally decline away within about 10-20 seconds (Patuzzi and Rajan, unpublished results; 9). The effects on these cochlear potentials are most likely to be exerted through changes in the resistance of the basolateral walls of the outer hair cells (7, 27). In contrast, an electrical stimulus applied to elicit OCB-mediated protection shows no such decrement in the protection elicited. An electrical stimulus applied for 30 seconds of a 1-minute-long loud sound exposure elicits only about half as much protection as does an electrical stimulus applied for the full duration of the exposure (15, 20). This result would suggest that the protective effects of the OCB, although being exerted through the MOCS synapses on OHCs, are not obtained through the same mechanisms as the MOCS effects on other cochlear potentials, i.e., through changes in the impedance of the basolateral wall. The long time-course of persistence of the protective effects suggests the possibility of involvement of biochemical changes rather than purely electrophysiological changes.

CONCLUSION.

On a comparative neurophysiological basis, these protective effects are rather analogous to the effects reported with stimulation of the efferent fibres to the lateral line system of the burbot *Lota Lota* (2). These fibres attenuate the responses of the lateral line organ and are most active during vigorous body movement rather than slow swimming. One role suggested (2) as a function for these fibres is to protect the afferent synapses from fatigue. This role is similar to the protective role described above for one component of the olivocochlear efferents in the three mammalian species tested to date.

Finally, it is significant to note that in cases of protection obtained with contralateral acoustic stimulation, the contralateral stimulus did not have to be presented at the same level as the ipsilateral damaging stimulus (1, 16, 18). Protection could be obtained even with the contralateral stimulus at a level up to 30 dB lower than the ipsilateral exposure. If there had been a requirement for the sounds to be of equal intensity in the two ears for protection to be elicited, translation of this requirement to the free field would mean that protection would only be obtained when loud sounds were in the midsagittal plane. Due to head-shadowing and pinna-amplification effects, sounds away from this axis would be at unequal intensities in the two ears, and protection would not be elicited. The fact that protection could be obtained even with inter-aural intensity differences of up to 30 dB makes it much more credible to extend the results obtained in these studies using closed sound field systems to the free field, since the value of 30 dB is very similar to the largest inter-aural intensity difference that can be recorded in the species used in the experiments described above. Indeed, in this context it has been reported (4) that free-field binaural exposures produce less damage than do free-field monaural exposures.

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Noise Induced Hearing Loss.

Summary remarks

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The purpose of this paper is to summarize recent advances in research and knowledge on Noise-induced Hearing Loss, NIHL, and to give emphasis to some aspects and urgencies for future research.
The topics of priority for Team 1 were structured according to the following list:

Topics of priority

A. Cochlear and Central mechanisms in NIHL

- **Pathophysiological basis for NIHL**
- **Central processes influencing NIHL**
- **Methods for measurement**

B. Interacting factors in NIHL

- **Aging**
- **Drugs**
- **Individ. variation and susceptibility**

C. Exposure factors in NIHL

Damage risk criteria

- **Continuous , intermittent and Impulsive Noise**
- **Critical exposure**
- **Recreational noise and noise from extraordinary sources**

D. Psychoacoustic measurements and Noise-Induced changes

- **TTS, ATS and PTS**
- **EHFA**
- **new invest techniques, other measures**

E. Hearing Conservation

- **HCP**
- **HPD**
- **Rehabilitation and Hearing Instrumentation in NIHL**
- **Prediction of vulnerability**
- **Training (=Toughening)**

At the Noise -88 meeting, where Flock (1) and Liberman (2) presented some pioneering contributions focusing on the active properties of the Outer Hair Cells (OHC) and the cochlea, very little was mentioned about the central processes that could possibly give influence on NIHL. The findings described by Cody and Johnstone (3), and Rajan and Johnstone (4) demonstrated that soundstimuli in one ear could modify the Temporary Threshold Shift (TTS) from loud sound exposures in the other ear. This might indicate the possible influence of efferent nerve stimuli in modifying the sound damage. Later on, Clark (5) and Canlon (6) in 1987-1988 described that noise training seemed to reduce the noise damage. These findings have started a new era in basic research and the topic of Central influences on NIHL was therefore organized into a particular workshop at this conference.

It appears that at least three central mechanisms may influence the effect of noise exposure to the ear. The middle ear or **acoustic reflex** (AR) has been known for years to have an influence on the noise exposure. In the frequency domain the AR is most effective for low frequencies. In the time domain it must be remembered that there is a time lag before the reflex exerts its full action, which means that it cannot have an influence on single impulses. At the meeting Borg (7) gave an overview of the properties of the AR demonstrating influences on impulsive noise already at a repetition rate of 3/s. There are pros and cons on the issue of the protecting role of the AR but the current view seems to support the argument that the AR plays an important role in protecting the ear against noise damage. Coletti et al (8), who support this opinion, have also suggested that it may be possible to use some measures of the reflex function as predictors of noise vulnerability.

Efferents mediated by the **medial olivocochlear (MOC) efferents** from the medial nuclei of the superior olivary complex seem to be the only source for efferent influences on the OHC (9). Extensive work on the protective properties of this system mediated through the crossed olivocochlear bundle has been done and was presented by Rajan at this conference (10). His paper together with Puel's presentations (11,12) described some of the recent advances in neurobiology that are of great importance for understanding the actions of the inner ear. The presentations also formed the background to Canlon's (13) and to Henderson's (14) presentations of sound conditioning or toughening and these findings are of utmost importance since they may contain new methods for avoiding or diminishing NIHL.

Most of our understanding of the cochlear and central mechanisms in NIHL emanate from animal studies. It seems quite clear that progress in knowledge so far would not have been possible without animal data. Our problem is to interpret these data transferred to other species and to human conditions. Dancer, who was the editor of the proceedings of the 4th Conference on NIHL held in Baune in 1990, made a great effort to present an overview of these difficulties (15,16). This interpretation is of utmost importance since also in the future we have to rely as much on information from animal data.

Under the heading methods there have been several reports of Otoacoustic emissions (OAE) in connection with NIHL. There is certainly a relationship between hearing level and otoacoustic emission. Apparently Distortion Products OAE (DPOAE) offers advantages over click-evoked OAE (TEOAE) by providing greater frequency specificity and more quantitative information about the degree of hearing impairment (17). Wilson (18) indicated that there is a strong relationship between NIHL and OAE but Avan (19) demonstrated that the OAE had an unacceptably low specificity with too many false negative answers (=Normal transient-

evoked OAE + NIHL audiograms). Thus there seems to be poor consistency in the results demonstrating reduction or abolition of the emission in response to NIHL as a sign of OHC-depletion. Avan suggested that further parameters of the OAE are needed than the mere presence or absence of the answer. However, the results of LePage and Murray (20) of early changes in OAE-responses as a sign of undue vulnerability to noise before any NIHL occurred are very interesting and the method needs further development.

Interacting factors in NIHL is an important topic. In this context aging has been most elaborately expressed in the database ISO 7029 (21) for age-correction of NIHL. According to ISO 1999 (22) this is done by subtraction of the presbyacusis values. The rationale for this strategy was supported by Mills (23) and Schmiedt (24). However, periods of higher susceptibility to noise seem to exist in the developing mammalian cochlea (25). There is suggestive evidence that this could affect the human fetus when exposed during pregnancy (26,27).

The interactions of noise and other agents are well known. Chemotherapeutic agents, ao. cisplatinum have been shown to have an affinity for the cochlea (28). Recent investigations demonstrate that noise (or cisplatinum) has a tremendous potentiating effect on the other agent (29). Salicylate does not seem to have a potentiating effect on the noise damage (27), whereas carbon monoxide resulted in interactive effects, possibly due to decreased oxygen concentration (30).
Organic solvents result in central disorders but the effect on the peripheral auditory system is more obscure ((29).

The extreme vulnerability continued to be an important issue at this conference. The reason for this is that intrinsic variability factors, such as eye colour, gender, age etc. or extrinsic such as variation of noise exposure (31) cannot alone explain the great variation. Henderson (32) has reviewed these variability factors including the recent views of toughening. According to Borg (33), susceptibility variation increases with intensity and he also emphasized that susceptibility to NIPTS varies over time. So far no single factor has so far been isolated that can explain the vulnerability.

Even though Criteria and standards have formed a new session organized by Team 9, there will always be aspects or results that may have an impact on the current criteria.

It seems that the current DRC - ISO 1999 gives a rough but acceptable risk evaluation for the exposed population. However, care must be taken from several points of view, when applying the database ISO 7029 since an erroneous choice of database carries the risk of overrating the NIHL, as emphasized by Lutman (34). He presented evidence that this risk may occur because of lack of adequate controls. Lutman's finding is very important and again indicates that the database in the riskdocuments has to be used with care. Thus, database A has been shown to be applicable in the Netherlands (35). Lutman's findings could indicate that without such proof, database B would be more appropriate to use in order to avoid overrating the risk of NIHL if normative data are lacking.
A similar problem was stressed by Ward (36), who demonstrated evidence that the hearing threshold levels of 18-year-old people entering the work force are worse than 0 dB and the same conclusion can be derived from Passchier-Vermeer's presentation (37). It is irrelevant whether the reason is hereditary (34), or caused by early aging (on hereditary basis?) or is of

leisure noise related origin (37). It causes an error of 2-6 dB by overrating the risk of subsequent NIHL. Related to this is the problem presented by Custard (38) that the U.K. was left with three different methods for predicting NIHL.

Altogether there is reason to conclude that the ISO 1999 document is valid for predictions on a statistical basis but that individual predictions must be used with care because of this extreme variability.
Passchier-Vermeer also indicated (37) that the fence for not suffering any NIHL seems more likely to be 75 dB(A), which means that a small percentage exposed daily to 80 $dBLA_{eq}$ will get a NIHL. This portion probably consists af the extremely vulnerable subjects.

Two other major problems with the ISO 1990 were also emphasized by Ward (36) i.e. impulsive noise is assumed to be equally hazardous as steady state noise and that by adopting the equal energy principle, the effect of temporal pattern of the noise exposure is ignored. NIHL caused by impulsive noise has been an important topic at the earlier congresses. Research results presented over the last ten years have greatly contributed to our understanding of this issue. Ward (36) gives emphasis to the fact that ISO-1999 declares all kinds of noise as equally hazardous as long as the energy content is the same. Also intermittence is disregarded by the risk document. Ward thus provided arguments against unlimited validity of the document.

For military purposes there has been a further need for risk criteria for impulsive noise. A research study group chaired by Smoorenburg has summarized their knowledge in a NATO report (39). Some important data have been presented such as the indication that the damage risk from large calibre weapons seems to be overrated and in contrast that reverberation around small-calibre weapons may be relatively hazardous (40).
One fascinating aspect of these data on impulsive noise was the indication of a nonlinear interaction where the low-frequency energy seemed to suppress the effect of the high-energy components. Liang (41,42) has also formulated a risk criterion for impulse noise based on human and guinea pig data. According to his calculations, the safety margin for man was 177 dB Peak equivalent SPL (with further compensation for impulse time and the number of rounds).

In her paper Passchier-Vermeer (37) presented an analysis of new data from exposures other than from occupational noise and emphasized music noise as a risk factor. There is no doubt that portable music equipment can produce noxious sound levels. Loth (43) in his paper calculated the Leq(8) to 101 dBA and similar figures (after compensation for head and ear canal amplification) have been reported earlier. There is clear evidence that some professional musicians may suffer occupational NIHL.
The risk for HL from pop music, rock music, disco music and Walkman music seems to be a controversial issue. Passchier-Vermeer earlier described this risk to follow the ISO 1999 predictions. Lindgren, however, reported less TTS from music than from corresponding white noise (44). Hellström and Axelsson have also found less HL in youngsters who reported the most extensive exposure to music noise than the subjects in the control group with little or no exposure (45,46).

The postulate that an assumed increase in incidence of HL was observed and should be attributed to leisure time music exposure (47) seems to be contradicted by another, controlled

investigation that has shown opposite results with no increase in incidence of a conscript material in Sweden (48). Apparently there is a need for more data from music exposures before a final evaluation of the risk of NIHL from music noise can be made.

The relation between TTS and PTS seems to be a subject for a neverending discussion. Mills stated that the ATS gives an upper bound estimate of the PTS and the correction factor can range from 0 to 8 dB or more (49). It can be derived from his results that the noise for a given ATS might be increased 0-8 dB in order to cause the corresponding PTS. Central influences on NIHL may have an impact on older data of TTS, ATS and PTS and the results have to be rechecked to see, whether a training effect may have compromised and influenced the conclusions. This was analyzed by Ahroon et al (50) who proposed a formula for describing the relation between TTS and PTS. It remains to be seen how well their model works.

Extra High Frequency Audiometry (EHFA) is still referred to as a method for early detection of NIHL. An interesting technique was described by Köhler (51) using Békésy-audiometry in the EHFA region making it possible to observe peak damage in this area. In this context Meyer-Bisch (52) described a new audiometric technique which also included analysis of the EHF. One drawback in EHFA measurements is the lack of consistency between various materials and normative data. In all EHFA measurements it is therefore advisable not to uncritically accept normative data from other laboratories but to have your own controls. Without exact knowledge of the variation in measurements with the equipment used it is hardly possible to draw any reliable conclusions. Long term studies could be valuable to determine whether the EHFA method could be developed for vulnerability evaluation.

Other psychoacoustic measurements to be mentioned under this heading are the investigations on TLS - Temporary Loudness Shift. Botte (53) has done a lot of work in this area and concluded that high level exposures result in two different types of fatigue:
(1) Type I Fatigue provides a maximum loss at frequencies higher than the exposure frequency from threshold to moderate audition level and
(2) Type II Fatigue has a maximum effect at low levels of test tones at the exposure frequency.
Low level noise exposures produce a slight increase in threshold and a noticeable loss of loudness at low test levels similar to type II. Her findings are interesting in the evaluation of the nature of the TTS and as a further step in the psychoacoustic features of NIHL, where there is a need for more research, especially for rehabilitation purposes.

Alberti's overview on Hearing Conservation Programs (HCP) was very important (54). Since treatment of damage to the always comes in the backwater because of the fact that it is not possible to restore the hair cells and the normal functioning of the inner ear, most effort must be devoted to prophylaxis - to hinder the noise from causing any damage:
1. by reducing the noise at the source
2. by means of better hearing protection
3. by transfers of the subject to less noisy work
4. by avoiding exposure of those subjects who have abnormal vulnerability.

We now have fairly good ideas of the constituents of effective HCP - but we rarely know how efficient these are in reality. It therefore seems essential to suggest the next step - viz.

on audit and on quality assurance. Eden's (55) paper concerning hearing conservation in the Australian mining industries is a step in this direction. It is important that ISO has set up a working group on this issue.

Hearing Protection Devices (HPD) always is a matter of importance at a meeting like this. For years, the low efficiency of HPD:s in practice has received much attention and there were also some important contributed papers on this issue at this meeting.
Military noise has come to be regarded as a special kind of occupational noise, definitely falling outside the frame of what is contained under ordinary work hazard rules. Patterson's group has presented a very interesting paper on the efficency of the hearing protectors under military conditions (56) demonstrating that protection was adequate for peak pressures above 180 dB SPL.

Active noise reduction technology (cancellation by phase shift) was developed and incorporated into headsets about 1989 and there is apparently a growing market for these devices(57). According to McKinley (58) a very effective attenuation is achieved and simultaneously there is a much better Speech Intelligibility (SI). Although this seems to be a good solution for those with normal hearing, a problem still remains with those subjects who have already suffered a NIHL and whose SI is severely reduced by the protectors (59). There is a great risk that subjects who already have a NIHL experience the communication problems to be of such dignity, that they will not use the HPD:s sufficiently. The benefit of the active noise reducing hearing protectors for these subjects has to be investigated. Maybe the solution is some kind of nonlinear hearing instrument with active noise reduction to promote the speech intelligibility (SI).
There were two presentations on rehabilitation. This urgent issue has previously been underrated at this conference. New developments in hearing instrumentation (HI) have been long needed (60). The fitting procedure is a difficult issue because of the risk for perceived occlusion of the ear (61).

As mentioned above, prediction of vulnerability is still one of the most urgent questions. Some 10 % of a population seem to develop a NIHL earlier and worse than the rest of the group who are exposed to similar noise. Methods for finding these subjects early in worklife, either for better hearing protection or for transfer to more quiet work surroundings are badly needed. So far, only repeated precision audiometry procedures have yet been useful for early detection of NIHL (62) and neither EHFA nor other measurements have yet been able to demonstrate any results that can be useful for detection of vulnerability before the damage is there. Whether early changes in the otoacoustic emission could be of value for prediction of undue NIHL (18) are therefore of utmost importance. More data in this area is urgently needed to find whether this is an useful approach.

It may be too early to discuss noise training or toughening as a part of Hearing Conservation. The results presented at this meeting at the workshop on "Central Control of Auditory system vulnerability to noise exposure" clearly indicate that a toughening effect can occur in the cochlea (6,13,14). The results have been found in several animal species after exposure to low-level noise. However, we still lack the parameters for the training parameters in order to be able to implement this in our HCP concept. These findings of training, conditioning and toughening appear as the most important progress of knowledge and understanding that have happened during the past five years since the last ICBEN meeting.

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Pertes auditives dues au bruit
Remarques de conclusion de la session 1

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Le but de cet article est de résumer quelques résultats récents de la recherche sur les pertes auditives dues au bruit (noise induced hearing loss ou NIHL) et de mettre en évidence certains aspects et certaines priorités des recherches futures.

Les sujets de l'atelier étaient structurés comme suit :

<u>A. Mécanismes cochléaires et centraux dans les NIHL</u>

- bases pathophysiologiques ;
- processus centraux influant sur les NIHL ;
- méthodes de mesure.

<u>B. Facteurs intervenant dans les NIHL</u>

- âge ;
- médicaments ;
- variations et sensibilité individuelles.

<u>C. Facteurs d'exposition</u>
Critères de risques de dommages

- bruit continu, intermittent et impulsionnel ;
- exposition critique ;
- bruit des loisirs, bruit de sources extraordinaires.

<u>D. Mesures psychoacoustiques et changements induits par le bruit</u>

- TTS (temporary threshold shift ou fatigue auditive)- ATS - PTS (permanent threshold shift ou perte d'audition);
- EHFA (audiométrie à très hautes fréquences);
- nouvelles techniques d'investigation.

<u>E. Protection de l'audition</u>

- HCP (hearing protection programs ou programmes de protection de l'audition);
- HPD (hearing protection devices ou protecteurs individuels);
- réhabilitation et instrumentation ;
- prévision de la vulnérabilité ;
- entrainement et endurcissement de l'oreille.

A la conférence de 1988, lorsque Floch et Liberman ont présenté quelques contributions d'avant garde sur les propriétés actives des cellules ciliées extérieures et de la cochlée, on parlait peu des processus centraux qui pouvaient influer sur les pertes auditives dues au bruit

Les recherches de Cody et Johnstone, Rajan et Johnstone ont montré que des stimuli sonores dans une oreille pouvaient modifier la fatigue auditive (TTS) due à une exposition à des bruits

élevés, dans l'autre oreille. Cela pourrait indiquer l'influence des stimulations du nerf efferent dans les modifications des dommages causés par le bruit. Plus tard, Clark et Canlon en 87-88 ont montré que l'entrainement au bruit semblait réduire les risques. Ces recherches ont été l point de départ d'une nouvelle ère dans la recherche fondamentale et le thème des "influence centrales dans les pertes auditives dues au bruit" a fait l'objet, d'un atelier particulier dans c congrès.

Il apparaît que 3 mécanismes centraux au moins peuvent influer sur les effets auditifs d'une exposition au bruit. Dans ce domaine, le réflexe acoustique (AR) de l'oreille moyenne est connu depuis des années. Dans le domaine des fréquences, ce réflexe est plus efficace pour les basse fréquences ; dans le domaine temporel, il faut rappeler qu'il y a un certain laps de temps avan que ce réflexe n'exerce toute sa fonction, ce qui signifie qu'il ne peut avoir de rôle protecteu dans le cas de bruits impulsionnels isolés. Borg a donné un aperçu des propriétés de ce réflexe acoustique, montrant son influence sur des bruits impulsionnels déjà à partir d'une répétitivité de 3 par seconde. Les avis sont partagés sur le rôle protecteur de ce réflexe, mais l'opinion la plus courante semble être en faveur d'un rôle important de protection de l'oreille contre les risques dus au bruit.

Collet et al, qui soutiennent cette hypothèse, ont également suggéré qu'il était possible d'utiliser certaines mesures de cette fonction réflexe comme indicateurs de prévision de la vulnérabilité au bruit.

Les efferents mis en oeuvre par les MOC (Medial olivochlear efferents) à partir des noyaux des complexes supérieurs semblent être la seule source d'influence sur les OHC. Un travail complet, présenté à ce congrès, a été effectué par Rajan sur les propriétés protectrices de ce système mis en oeuvre par l'intermédiaire du système olivocochléaire. Son article, ainsi que la présentation de Puel (11,12) décrit quelques aspects des progrès récents de la neurobiologie qui sont d'une grande importance pour la compréhension des comportements de l'oreille interne. Ces aspects servent également de base aux présentations de Canlon (13) et Henderson (14) sur le conditionnement et l'entrainement aux bruits et ces découvertes sont capitales dans la mesure où elles peuvent induire de nouvelles méthodes pour éviter ou diminuer les pertes auditives dues au bruit.

Beaucoup de nos connaissances sur les mécanismes cochléaires et centraux proviennent de recherches sur l'animal. Il est évident que les progrès dans notre compréhension n'auraient pas été possibles sans informations sur l'animal . Notre problème est d'interpréter ces informations et de les transférer à d'autres espèces et à l'homme. Dancer, qui a édité le compte-rendu de la 4ème conférence sur les pertes auditives dues au bruit, tenue à Beaune en 1990, a fait un gros travail de synthèse sur les difficultés rencontrées dans ce domaine (15,16). Cette interprétation est très importante puisque, même dans le futur, nous aurons à compter encore sur des données provenant d'études sur l'animal.

Sous le sous-titre "Méthodes", plusieurs conférences ont porté sur les otoémissions en rapport avec les pertes auditives dues au bruit. Il y a sans doute une relation entre le niveau d'audition et l'émission otoacoustique. Apparemment, les DPOAE (distortion products otoacoustic emissions) offrent des avantages par rapport aux TEOAE, en fournissant une plus grande spécificité fréquentielle et plus d'information quantitative sur le degré de détérioration (17). Wilson (18) a indiqué qu'il y a une relation forte entre la perte auditive et l'émission otoacousique, mais Avan a démontré que l'otoémission avait une faible spécificité avec beaucoup de fausses réponses négatives (normal transitoire - OAE évoqué + audiogramme de perte auditive). Ainsi, il semble qu'il y ait peu de cohérence dans les résultats, tendant à démontrer une réduction ou une disparition de l'émission en réponse à la perte auditive, comme signe d'épuisement des cellules ciliées externes.

Avan pense que d'autres paramètres de l'otoémission sont à prendre en compte, plutôt que simplement présence ou absence de réponse. Toutefois, les résultats de Lepage et Murray (20) sur les changements précoces de réponses d'otoémission comme signes d'une vulnérabilité excessive avant même l'apparition d'une perte d'audition, sont très intéressants et la méthode nécessite d'être développée dans le futur.

Les autres facteurs agissant sur les pertes d'audition dues au bruit, constituent un sujet important.

Dans ce domaine, l'âge a été pris en compte expressément dans la norme ISO 7029 (21) par l'introduction d'un terme correctif. Selon la norme ISO 1999 (22), ceci s'effectue par soustraction par rapport aux valeurs de presbyacousie. La base de cette stratégie est fournie par les travaux de Mills et Schmidt (24). Toutefois, il semble qu'il existe des stades de plus grande sensibilité au bruit dans le développement de la cochlée des mammifères. Des preuves certaines que cela peut affecter le foetus ont été mis en évidence (26-27).

L'interaction du bruit et d'autres agents est bien connue. On a montré que certains médicaments, par exemple le cisplatinum, ont des affinités pour la cochlée (28). Des recherches récentes montrent que le bruit (ou le cisplatinum) a un effet potentialisateur extraordinaire sur l'autre agent.

Le salicylate ne semble pas avoir d'effet potentialisateur sur le dommage auditif (27) alors que le monoxide de carbone a des effets dus probablement à une diminution de la concentration en oxygène (30). Les solvants organiques provoquent des désordres centraux mais l'effet sur le système auditif périphérique est plus obscur.

L'extrême sensibilité au bruit est encore restée un sujet important de ce congrès. La raison en est que des facteurs intrinsèques de variabilité tels que la couleur des yeux, le sexe, l'âge etc... ou des facteurs extrinsèques ne peuvent pas à eux seuls expliquer les importantes variations. Henderson (32) a passé en revue tous ces facteurs de variabilité, incluant les points de vue récents sur l'endurcissement *au bruit par entraînement.*

Selon Borg (33), la variation de la sensibilité augmente avec l'intensité ; il a montré également que la vulnérabilité et la fatigue auditive varient dans le temps. Aucun facteur unique n'a pu être jusqu'à présent isolé qui puisse expliquer cette vulnérabilité.

Bien que le thème "critère et normes" fasse maintenant l'objet d'une session séparée, (équipe N°9), il y aura toujours des aspects ou des résultats qui auront un impact sur les critères retenus comme seuils.

Il semble que la norme DRC-ISO 1999 donne une évaluation du risque pour les populations exposées un peu grossière mais néanmoins acceptable. Toutefois, on doit prendre des précaution lorsqu'on applique l'ISO 7029 car un choix erroné de données entraine un risque de surévaluation de la perte auditive, ainsi que le démontre Lutman (34). Il a apporté la preuve que ce risque peut apparaitre par manque de contrôles adéquats. Les résultats de Lutman sont très importants et indiquent de nouveau que la base de données dans les documents d'évaluation des risques doit être utilisée avec précaution. Ainsi, la base de données A s'est révelé applicable aux Pays-Bas (35). Les travaux de Lutman peuvent indiquer que, sans cette preuve, la base de données B serait plus appropriée pour éviter de surévaluer le risque de pertes auditives dues au bruit, si l'on ne dispose pas de données normatives.

Un problème similaire a été soulevé par Ward (36) qui a mis en évidence le fait que les seuils d'audition des jeunes de 18 ans entrant dans la vie professionnelle sont mauvais (pire que 0 dB) et on peut tirer la même conclusion des travaux de Passchier-Vermeer's (37). Il n'est pas pertinent de savoir si la raison est héréditaire (34), causée par l'âge (sur une base héréditaire ?)

ou due aux loisirs bruyants (37).Cela entraine une erreur de 2 à 6 dB par surestimation du risque d'effets auditifs dus au bruit. Lié à cet aspect, il y a le problème, présenté par Custard, de la Grande-Bretagne qui possède 3 méthodes différentes de prévision des pertes auditives dues au bruit.

Dans l'ensemble, on peut conclure que la norme ISO 1999 est valable pour la prévision sur une base statistique, mais les prévisions pour les individus doivent être utilisés avec précaution en raison de cette extrême variabilité.

Paschier-Vermeer a indiqué aussi que la limite pour ne pas avoir de trouble quelconque de l'audition se situe plutôt aux alentours de 75 dB (A), ce qui signifie qu'un faible pourcentage de personnes exposées quotidiennement à 80 dB en LAeq sera victime de troubles de l'audition. Ce pourcentage est certainement constitué des sujets extrêmement vulnérables.

Deux autres problèmes importants concernant l'ISO 1999 ont été mis en évidence par Ward (36), à savoir que les bruits impulsionnels sont considérés comme aussi dangereux que les bruits continus, et que, en adoptant le principe de l'énergie équivalente, l'effet du schéma temporel sur l'exposition au bruit n'est pas pris en compte. Les surdités dus aux bruits impulsionnels ont constitué un sujet important au cours des congrès précédents. Les résultats des recherches présentés au cours des 10 dernières années ont beaucoup contribué à nous faire comprendre ce phénomène. Ward (36) insiste sur le fait que l'ISO 1999 considère tous les types de bruit également dangereux dès lors que le contenu énergétique est le même. Les bruits intermittents ne sont pas pris en compte dans le document sur les risques. Ward considère donc que ce document n'a pas une validité absolue.

Pour des raisons militaires, il a été nécessaire de rechercher d'autres critères pour les bruits impulsionnels. Un groupe de recherche présidé par Smorenburg a résumé ses travaux dans un rapport de l'OTAN (39). Des informations importantes ont été présentées, telles que le fait que les dommages provoqués par les armes à gros calibre semblent être surestimés, et qu'au contraire la réverbération autour des armes de petit calibre est peut-être relativement dangereuse

Un aspect fascinant de ces informations sur les bruits impulsionnels est qu'il existe une interaction non linéaire qui fait que l'énergie en basse fréquence semble supprimer l'effet des composantes haute fréquence. Liang(41-42) a aussi formulé un critère de risque pour les bruits impulsionnels basé sur des recherches menées sur le cobaye et sur l'homme. Selon ces calculs, la marge de sécurité pour l'homme est de 177 dB en niveau de crête équivalent SPL (avec une compensation supplémentaire pour la durée de l'impulsion et le nombre d'impulsions).

Dans sa conférence, Passchier-Vermeer (37) a présenté une analyse de données nouvelles sur les expositions non professionnelles au bruit et a mis en évidence le rôle de la musique comme facteur de risque. Il n'y a aucun doute : les équipements portables peuvent produire des niveaux dangereux. Loth (43) a trouvé des Leq (8) de 101 dB (A) et des chiffres similaires (après compensation pour tenir compte de l'amplification du conduit auditif) ont déjà été trouvés. Il est clair que certains musiciens professionnels peuvent souffrir de surdités professionnelles.

Les risques dus à la musique pop, rock, disco et aux baladeurs constituent un sujet controversé. Passchier-Vermeer avait montré précédemment que ces risques suivaient les modèles prévisionnels de l'ISO 1999; Lindgren, toutefois, a trouvé moins de fatique auditive due à la musique qu'à un bruit blanc correspondant (44).

Hellström et Axelsson ont également trouvé moins de pertes auditives chez les jeunes exposés intensivement à de la musique que les sujets du groupe contrôle peu ou pas exposés (45-46).

L'hypothèse selon laquelle on aurait observé une augmentation de pertes auditives pouvant être attribuée à une exposition à la musique (47) semble être contredite par une autre recherche,

menée en Suède sur les jeunes recrues du régiment, montrant des résultats opposés, sans augmentation d'incidence (48).

Apparemment, il serait nécessaire de disposer d'informations supplémentaires sur ce sujet avant de pouvoir évaluer le risque de pertes auditives dues à la musique.

La relation entre fatigue auditive temporaire ou définitive (TTS et PTS) semble être l'objet de discussions sans fin. Mills a montré que l'ATS donne une estimation à la limite supérieure du PTS et le facteur de correction peut s'échelonner de 0 à 8 dB ou plus (49).On peut déduire de ces résultats que le bruit, pour un ATS donné, peut être augmenté de 0 à 8dB pour correspondre au PTS. Des influences centrales sur les pertes auditives peuvent avoir un impact sur des données antérieures de TTS, ATS et PTS et les résultats doivent être recontrôlés pour voir si un effet d'entraînement peut avoir compromis et influencé les conclusions. Ceci a été analysé par Ahroon et al (50) qui ont proposé une formule pour décrire la relation entre TTS et PTS; il faut encore voir si leur modèle fonctionne.

L'audiométrie très haute fréquence est toujours considérée comme une méthode permettant de détecter de façon précoce une perte auditive due au bruit. Une technique intéressante a été décrite par Köhler (51) utilisant l'audiométrie-Békésy dans la région des très hautes fréquences qui permet d'observer les dommages maximum dans cette zone.

Dans ce contexte, Meyer-Bisch (52) a décrit une nouvelle technique audiométrique qui comprend aussi une analyse en très hautes fréquences. Un inconvénient des mesures en très hautes fréquences est le manque de cohérence entre les divers matériels et les données normatives. Dans toutes les mesures hautes fréquences, il est par conséquent conseillé de ne pas accepter automatiquement les informations les autres laboratoires, mais plutôt d'avoir ses propres contrôles. Sans connaître exactement la variation des mesures compte-tenu de l'équipement utilisé, il est presque impossible de tirer des conclusions fiables. Des études à long terme pourraient être utiles pour déterminer si la méthode des audiométries en très hautes fréquences peut être développée dans le but d'évaluer la vulnérabilité des personnes.

Dans ce chapitre, d'autres mesures psychoacoustiques doivent être mentionnées ; ce sont des recherches sur le TLS - Temporary loudness shift - ou variation temporaire de la sonorité.

Botte a fait un grand travail dans ce domaine et a conclu que les expositions à de hauts niveaux provoquent deux types de fatigue :

1) la fatigue de type I engendre une perte maximum à des fréquences supérieures à la fréquence d'exposition, depuis le seuil jusqu'à un niveau modéré d'audition ;

2) la fatigue de type II a un effet maximum à des niveaux faibles, à la fréquence d'exposition.

Des expositions à des niveaux faibles provoquent une légère augmentation du seuil et une perte notable de la sonorité à des niveaux de test peu élevés similaires au type II.

Les recherches sont intéressante pour l'évaluation de la nature des fatigues auditives et constituent un pas supplémentaire dans le domaine des caractéristiques psychoacoustiques des pertes auditives, domaine dans lequel des études supplémentaires sont nécessaires.

La synthèse d'Alberti sur les programmes de protection de l'audition est très importante. Le traitement des dommages n'était pas vraiment adéquat puisqu'on ne sait pas réparer les cellules ciliées ni restaurer un fonctionnement normal de l'oreille interne, les efforts doivent plutôt se porter sur la prévention.

Il s'agit d'empêcher les effets néfastes du bruit :

1) en réduisant le bruit à la source

2) en fournissant une meilleure protection de l'oreille

3) en transférant le sujet vers un poste de travail moins bruyant

4) en évitant d'exposer au bruit des sujets présentant une vulnérabilité anormale.

On possède maintenant une bonne idée des constituants d'un programme de protection contre le bruit, mais on sait rarement leur efficacité réelle.

Il apparait donc essentiel de suggérer la prochaine étape, c'est-à-dire l'audit et l'assurance qualité. La conférence d'Eden sur les programmes de prévention dans les industries minières australiennes marque un pas dans cette direction.
Il est intéressant que l'ISO ait créé un groupe de travail sur ce sujet.

Le thème des protecteurs individuels est toujours d'importance dans ce type de congrès.Depuis des années, la faible efficacité des protecteurs individuels sur le terrain retient l'attention de tous les chercheurs, et cette année encore plusieurs conférences ont traité de ce problème.

Le bruit d'origine militaire est désormais considéré comme une catégorie de bruit professionnel, dépassant complètement le cadre habituel des risques liés à un travail ordinaire. Le groupe de Patterson a présenté une recherche très intéressante sur l'efficacité des protecteurs utilisés dans des conditions militaires (56) montrant leur efficacité pour des niveaux de crête au dessus de 180 dB SPL.

La technologie de l'absorption active a commencé à être incorporée dans des casques de protection aux alentours de 1989 et il y a apparemment une demande croissante pour ces produits (57).

Selon McKinley (58) on obtient simultanément une atténuation très efficace et une meilleure intelligibilité de la parole. Bien que cela apparaisse comme une bonne solution pour les personnes ayant une audition normale, le problème subsiste pour les sujets ayant déjà souffert de perte d'audition due au bruit et pour lesquels l'intelligibilité est terriblement réduite avec les protecteurs (59). Les sujets ayant déjà une perte d'audition risquent fort de se heurter à ce problème de communication et par conséquent de ne pas porter leurs protecteurs de manière suffisante. Il faut étudier l'efficacité des systèmes à absorption active pour ce type de population.

Deux conférences ont porté sur la réparation. Ce sujet grave avait été sous-estimé dans les précédentes conférences. De nouveaux développements dans l'intrumentation ont été longtemps nécessaires (60). C'est une procédure difficile à cause du risque d'occlusion de l'oreille (61).

Ainsi que nous l'avons mentionné plus haut, la prévision de la vulnérabilité demeure une des questions les plus pressantes. Environ 10% de la population semblent avoir une perte d'audition due au bruit plus précoce et plus grave que le reste du groupe exposé à un bruit similaire. Des méthodes permettant de détecter ces sujets très tôt dans la vie professionnelle, pour pouvoir les protéger ou les transférer dans des environnements plus calmes, sont à trouver de façon urgente. Jusqu'à présent, seuls des examens audiométriques précis et répétés ont permis une détection précoce (62) et ni les mesures en très hautes fréquences ni d'autres mesures n'ont permis d'apporter des résultats dans la détection de la vulnérabilité, avant que les dommages ne soient déjà là. Il serait très utile de savoir si les changements dans les otoémissions peuvent

permettre de prévoir une perte auditive. Des informations complémentaires sont absolument nécessaires pour déterminer s'il est utile de continuer sur cette voie.

Il est peut-être encore trop tôt pour discuter de l'entraînement et de l'endurcissement au bruit, comme méthodes de prévention. Les résultats présentés au cours de ce congrès dans l'atelier "Contrôle central de la vulnérabilité du système auditif au bruit" indiquent clairement qu'un effet de durcissement peut se produire dans la cochlée (6,13,14). Ces résultats ont été trouvés dans diverses espèces animales après exposition à des bruits de faible niveau. Toutefois, nous ne connaissons toujours pas les paramètres de cet entraînement de l'oreille qui nous permettraient de les inclure dans nos programmes de protection de l'audition. Ces découvertes sur l'entraînement, la mise en condition et l'endurcissement de l'oreille, apparaissent comme les progrès les plus importants enregistrés depuis le dernier congrès ICBEN, il y a cinq ans, dans la connaissance et la compréhension des phénomènes de l'audition.

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Noise and Communication: general introduction

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Summary

The theme "Noise and Communication" covers a wide range of topics, all related to some form of communication (e.g., speech or warning signals), under the influence of one or more disturbing factors, with the emphasize on the effect of ambient noise. Such topics may include characteristics of the source signal (speech, either direct or via telephone or Public-Address systems, or specific warning sounds), characteristics of the environment (ambient noise, reverberation), or of the listener (native versus non-native language, hearing loss, the use of ear-protection devices). A systematic overview of this field will be presented, indicating the areas for which design criteria and guidelines are readily available, and areas for which more research is needed.

This academic approach of identifying "areas which require more research", will be supplemented by a more pragmatic approach: Formulate a variety of practical questions related to our field of expertise, and see to what extend we can supply the necessary information for answering these questions. Examples of such questions are: (1) specify the characteristics of a warning signal for a noisy working environment, to be recognized and localized by young people using ear plugs, or (2) what design criteria should be used for a Public-Address system in a noisy and reverberant environment for an audience including elderly and non-native listeners? This pragmatic approach provides interesting information on the relevance and the (in)completeness of the expertise in the field of noise and communication.

The first viewgraph presents an overview of the various elements involved in the chain of communication (source, environment and listener). Noise, as part of the environment, is only one of these many elements. Since communication depends on so many additional factors, the aspect "noise" cannot be considered in isolation: *There is no simple absolute noise level criterion which guarantees satisfactory communication.*

Viewgraph 1. "Noise" as one element in the chain of communication.

COMMUNICATION:

SOURCE	* Speech (direct, *via telephone or PA, or synthetic*)
	* *Warning signal* (detection, recognition, localization)
ENVIRONMENT	* *Noise* (temporal and spectral characteristics)
	* *Acoustics* (reverberation, sound transmission)
LISTENER	* Hearing loss, elderly
	* *Hearing aids*
	* *Hearing protection*
	* Non-native listener

Note: Factors controlled to some extend by designers (technicians, acousticians) are indicated in Italics.

In general terms, the AIM of our research is:

* To provide guidelines for the designer to realize conditions for satisfactory communication.
* Also: To provide a framework of reference for the purpose of legislation and planning.

The field is multi-disciplinary and interactive, as may be illustrated by the following viewgraph:

Viewgraph 2. Two examples illustrating the interactive nature of the field Noise and Communication.

Example 1:

"Realize a PA-system in a noisy environment for the communication of short messages"

Besides the characteristics of the ambient noise (level, spectrum), the result depends on the speech level produced by the PA-system, the configuration of the loudspeakers, the sound absorption in the room, etcetera.

Example 2:

"Provide moving vehicles in a noisy industrial plant with a warning signal which can be well localized by individuals using hearing protection"

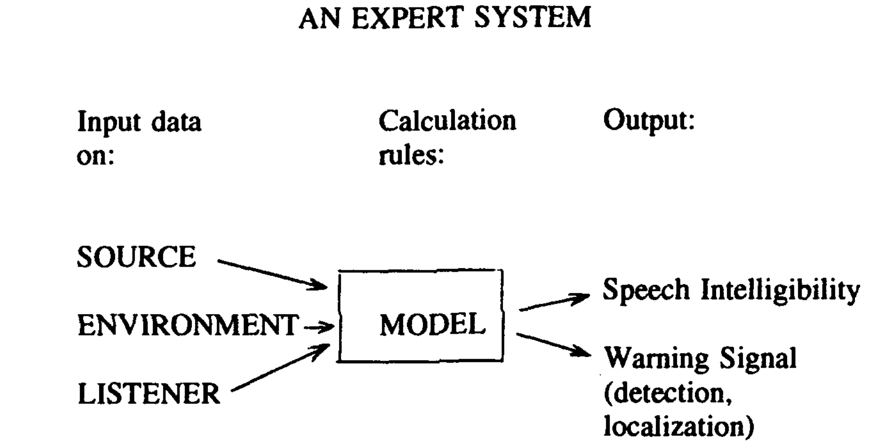
Again, besides the noise other factors are involved, as the characteristics of the warning signal, the choice of the type of hearing protection, and others.

These examples illustrate that, in stead of reducing the noise level, the same effect may be obtained by, for instance, increasing the amount of loudspeakers, adding more sound absorbing material, choosing an appropriate type of warning signal, or other measures.

To arrive at a most cost-effective solution, one needs to know the effect of the individual factors, and their interactions.

One way of structuring our knowledge, and making it accessible, is by building an Expert System. For a given situation, by specifying all the relevant input data on the characteristics of source, environment and listener, such an Expert System can provide predictions in terms of speech intelligibility and signal detection, as illustrated below. Of course, the success of such a model will depend on the validity of the calculation rules by which the input data are translated and interpreted in terms of the output variables. ***The very process of modelling and evaluating such an EXPERT SYSTEM provides an opportunity to identify loose ends in our knowledge on noise and communication.***

Viewgraph 3. The structure of an Expert System on Noise and Communication.



All papers presented in this Session do relate, directly or indirectly, to the building stones of such an Expert System. We will learn that much knowledge is available, be it rather fragmented and discipline-specific. What we need at this point is an integration of the various building stones. I will come back to this point in my Summary, at the end of this Meeting.

RECOGNITION OF DANGER SIGNALS AND SPEECH COMMUNICATION - STATE OF STANDARDISATION

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Summary

Speech communication is an important part of the activity at work, in school, at home and during leisure time. Recognition of warning signals is a part of the safety system for work and traffic.

The technical comittees of ISO and CEN deal with these subjects. ISO/TC43 'Acoustics' presents a standard concerning emergency signals. ISO/TC159 and CEN/TC122 'Ergnomics' have prepared standards for a system of danger signals with sound and light, requirements on acoustic danger signals, an assessment of speech communication with the speech interference level.

These standards include the influence of ambient noise, signal-to-noise ratio, frequency and temporal pattern of auditory signals, wearing of hearing protectors, speaker's vocal effort, shouted speech and hearing loss. The methods described in these standards to assess the speech communication and their advantages are discussed.

1. Introduction

Signals describe situations and objects (machines) so that they can be classified.

In plants and when machines are being operated, information is given on the work process itself and on dangers which arise. In many cases the information, and in particular that on safety aspects, is depicted and passed on by means of a signal. Encoded as it is according to established rules, the signal contains the essential information.

In relation to safety, the signals describe danger situations in the proximity of machines or in whole plant zones.

2. Ergonomic guidelines for danger signals

In plants, in public traffic and in the case of disasters, acoustic and optical signals are used to impart information and give a warning.

In all standards concerned with the form of danger signals, the following principles have been laid down:

The signals must be capable of being recognized quickly and reliably even under difficult environmental conditions, i.e.

- the signals must be perceptible,
- the signals must be identifiable as such,
- the meaning of the signal must be recognised,
- the signal must be clear and capable of being allocated to the danger or the necessary action,
- the signal must be distinguishable from other signals and sources of interference.

From these principles for the reliable and fast recognition of signals, one obtains guidelines for the form of signals. In the physical form and coding of signals, account has to be taken of the laws of perception for human beings. The degree of urgency of a danger situation is to structure the form of the signals.

The standard EN 50099-1 describes requirements for the kind of visual, auditory and tactile signals to be used for displays and operating parts on machines.

In a number of cases, the danger situation can be indicated directly at the man-machine interface. In many cases, it is necessary, however, to encode the information on the danger situation and to impart it via a signal. The reasons for the use of coding may be:

- the spatial separation of machine and control system,
- to increase the amount of information imparted, e.g. per display area, per time unit,
- to lower the mental workload for the operator and exposed persons.

The safety-related information must be shown by the relevant means in such a way that the capacities of the operator or person at risk enable him to recognize the signal.

It is explained, for example, that, in addition to visual signals, auditory and tactile signals have to be selected if

- the signal is not easily recognisable because of an excess of other information;
- visible signals alone are not sufficient, because
    + the operator has to look elsewhere while operating,
    + the exposed persons are out of sight of the operation,
    + the exposed persons cannot see the warning signals.

In some work it was investigated to what extent the specific frequency distribution and the temporal pattern, and the known auditory danger signals are capable of being used as danger signals (Bock et al. 1983, Lazarus, Höge 1986, Edworthy et al 1991). The results of this work were in part the basis for the following standards described.

3. Ergonomic principles for auditory and visual danger signals (ISO 11429, prEN 50099-1)

The standard ISO 11429 describes a system of visual and auditory danger signals which can be applied for all degrees of urgency (from utmost urgency to the "all clear").

For auditory and visual signals, feature classes are formed with the help of physical parameters and allocated to these urgency levels of the danger situations.

4. Requirement for the form of auditory danger signals (EN 457/ISO 7731)

A number of basic principles have been defined for dealing with auditory danger signals.

Auditory danger signals indicate the beginning, if necessary the duration, and the end of a danger situation.

A distinction is drawn between two types of danger, depending on the urgency and possible consequences for individuals: warning signals and emergency evacuation signals. The warning signal indicates the possibility or actual presence of a danger situation and involves the demand to take suitable action to reduce the danger. The emergency evacuation signal indicates the beginning or presence of an emergency situation with the direct possibility of injury and calls on the individuals to leave the danger zone.

The signal reception range is defined by the spatial area in which the individuals have to recognize the signal and should react to it.

The masked threshold is described as the sound pressure level at which the danger signal is just audible in interfering noise, if necessary taking into account a loss of hearing and the wearing of hearing protectors.

Rules for the form of the danger signal are described as safety requirements.

Requirements: The nature of the auditory danger signal must be such that every individual in the signal reception area can recognize the signal and react to it in the way intended.

Auditory danger signals must have priority over all other acoustic signals with regard to recognisability.

An auditory emergency evacuation signal must have priority concerning recognition over all other warning signals.

Care must be taken to ensure that the effectiveness of the auditory danger signal is checked at regular intervals.

Recognition: The reliable recognition of an auditory danger signal requires that the signal is clearly audible, can be adequately distinguished from other sounds in the environment, and have an unambiguous meaning.

Audibility: The signal must be clearly audible. It must exceed the masked threshold. This can as a rule be achieved when the A-weighted sound pressure level of the signal exceeds the ambient noise level by 15 dB or more.

When octave band analysis is used, the sound level must exceed the masked threshold level in one or more octave bands by at least 10 dB.

Discriminancy: At least two of the acoustic parameters of danger signals (sound level, temporal pattern, frequency distribution) which influence the discriminancy of the signals must be distinct in a decisive way from those of other signals in the signal reception area and from the interfering noises.

Unambiguity: The meaning of the auditory danger signal must be unambiguous. Auditory danger signals and signals serving other purposes must not be in accord.

The masked threshold can be determined by approximation from the octave band levels of the interfering noise.

It should be stressed that, under this standard, the manufacturer of signal devices should indicate the following in data sheets:

- the sound power level (L_{WA})
  (if necessary the A-weighted sound pressure level measured at a distance of 1 m from the source in the main direction of radiation ($L_{SA,1m}$),
- the maximum value of the octave sound pressure level ($L_{s,oct,1m}$) in the main direction of radiation
- the 1/3 octave band or narrow band spectrum ($L_{s,t,1m}$).

The test as to whether a signal is suitable can be conducted on the basis of the following measurements and data indications:

- Indications of the sound emission of the signal device (L_{WA}; $L_{S,oct,1m,max}$; $L_{s,t,1m}$);
- Indications concerning the workplace:
  - distance from the signal device,
  - interfering noise ($L_{N,A}$; $L_{N,oct}$),
  - listening check in the signal reception area.

Mention should be made of a number of rules for the form of danger signals:

Sound pressure level	L_{pA}	=	65 to 110 dB
Signal-to-noise ratio	L_{SA}-L_{NA}	=	15 dB
Signal level to masked threshold difference	$L_{S,oct}$-$L_{T,oct}$	≥	10 db
Temporal distribution	pulsating preferred to continuous		
Rise in level	L_{pA}	≤	30 dB in 0.5 s
Frequency range			0.3 to 3 kHz
Main energy in the frequency range			< 1.5 kHz
Frequency distribution (pitch)	sweeping preferred to continuous		
Pulse frequency			0.2 to 5 Hz

Urgency can be provoked by fast rhythm, dissonance and high frequencies.

5. An acoustic emergency evacuation signal (ISO 8201)

The acoustic emergency signal was developed on the basis of ISO 7731/EN 457 by ISO-TC 159 (Ergonomics) and ISO-TC 43 (Acoustics). Since this signal is to apply for all workshops and buildings, it is not possible to adjust it to the many different background noises present so that it is recognisable under most environmental conditions, i.e. audible, distinguishable and unambiguous. In this standard it was possible to find agreement on a rough acoustic model, the temporal pattern is pregiven: three times alternating 0.5 s on and 0.5 s off and then 1 s off. In the "on phase", different signals can be used according to the national or plant-based specifications or according to the frequency distribution of the interfering noise. It is recommended to have temporal patterns in the "one phase" with frequency changing sweeping or in steps.

In a German standard (DIN 33401 Part 3), a signal with sweeping falling frequency (f_1 = 1.2 Hz; f_2 = 0.5 kHz) and a signal-to-noise ratio of L_{SNA} = 10 dB are laid down.

6. Ergonomic assessment of direct speech communication (ISO 9921)

This ISO standard describes the assessment of the quality of speech communication, e.g. at workplaces for persons with normal hearing capacity in direct communication.

The main problem in drawing up this standard was the description and definition of the large number of influencing parameters acting on speech communication. The following physical and personal influencing parameters are mentioned:

Physical parameters
- Sound pressure level, frequency distribution and temporal pattern of the interfering noise,
- Room acoustics (e.g. reverberation time),
- Distance between the speaker and the listener,
- Visual contact between the communicating partners,
- Effects of hearing protectors.

Personal parameters
- The type of language (the language of the speaker, dialect, vocabulary),
- The listener's knowledge of and familiarity with the message articulated (size and selection of vocabulary, specific word groups),
- Effective language signals (clarity of pronunciation, vocal effort, speaking speed),
- Hearing characteristics of the listener (hearing capacity, directional hearing, over-loading),
- The motivation of speaker and listener (expectations, fatigue, stress).

For part 1 of the standard, which is only concerned with direct speech communication for persons with normal hearing capacity, the following influencing parameters are laid down:

Physical conditions
- The reverberation time is less than 2s at 500 Hz.
- The direction of speaking should be towards the listener.

- The visual axis of the listeners is arbitrary.
- There is no lip-reading.
- Electro-acoustic transmission systems are excluded.
- Effect of hearing protectors on the speaker.

Personal conditions
- Hearing with both ears,
- Normal hearing capacity according to ISO 7029,
- Speaker and listener are familiar with the language and the speech message,
- Clarity of pronunciation (see ISO/TR 4870),
- Speech message consists of monosyllabic words to describe the worst case, such words are used because they are largely independent of language and semantic; to convert speech intelligibility for monosyllabic words to sentences, see also ISO/TR 4870.
- Decrease of the speech intelligibility at high noise levels.

The results of this standard can be applied to normal conversation, conversation with restricted vocabulary and simple warning calls and commands.

Crucial for assessing the quality of speech communication is the signal-to-noise ratio on the side of the listener and the effort made by the speaker, the level of the interfering noise and the distance between the speaker and listener being particularly important.

The vocal effort of the listener arises through the Lombard effect. It is also taken into account that loudly spoken and shouted speech is more difficult to understand. The influence of hearing protectors of the speaker is included for high noise levels ($L_{N,A} \geq 75$ dB).

For satisfactory speech communication, the relation between ambient noise level, vocal effort and maximum distance between speaker and listener is given in a figure.

For a major portion of areas of life and workplaces the quality of the necessary speech communication is particulary important. Thus a very high quality of speech communication will be demanded for dwellings, meeting rooms or workplaces where the essential information is imparted by means of speech. At workplaces, for example assembly workplaces, where language is only necessary now and again for the work involved, only a low quality of speech communication is required. To assess the quality of communication, the necessary vocal effort, measured as the A-weighted sound pressure level of the speaker at a distance of 1 m from the mouth ($L_{sp,A,1m}$) is taken on the one hand. On the other, the permitted noise derived from the signal-to-noise ratio needed for the hearer is used (see Table 1).

a		b	
Vocal effort	$L_{SA,1m}$ in dB	Assessment	$L_{S,A,L} - L_{N,A,L}$ in dB
max. shout	90	insufficient	< -6
shout	84	unsatisfactory	-6 ... -3
very loud	78	sufficient	-3 ... 0
loud	72	satisfactory	0 ... 6
raised	66	good	6 ... 12
normal	60	very good	12 ... 18
relaxed	54	excellent	> 18

Table 1 (a): Vocal effort of the speaker and its assessment, (b): The A-weighted signal-to-noise ratio ($L_{S,A,L} - L_{N,A,L}$) at the listener's position and its assessment with respect to speech intelligibility (acc. to ISO 9921)

The criteria for the assessment of speech communication were obtained from a very carefully conducted analysis of the literature of the last 10 to 15 years (see ISO 9921-1; Annex C).

For the Articulation Index (ANSI S3.5-1969), a revised version is meanwhile available as a draft (ANSI S3.79-1992). To precisely determine speech communication, and in particular the speech communication through electro-acoustic systems, it is planned to draw up a Modified Articulation Index (Lazarus 1990). The Speech Transmission Index can be measured according to the RASTI method (IEC 268-16) which is primarily used for auditories.

7. Minimum regulations for safety and health signs at the workplace (EC directive 92/58)

Under this directive, the employer is obliged to provide safety signs at the workplace as laid down in the directive, if the risks cannot be avoided by collective technical or organisational measures. Annexes describe proposals for prohibition signs, warning signs, command symbols, notices and for plates, safety colours, pictorial signs, illuminated signs, acoustic signals, verbal communication and hand signs.

Annex VII only contains very general, and unfortunately partly contradictory stipulations for acoustic signals. The acoustic signal must be distinctly louder than the ambient noise so as to be clearly audible. On the one hand, a signal with sweeping frequency is preferred for a higher danger level (para 1. 2)); on the other hand, a continuous tone should be used for evacuation purposes (para 2).

Annex VIII on verbal communication only contains a number of general stipulations, which can be regarded as a basic prerequisite for speech communication. So it is said that people have to master the language, in order to properly express and understand the verbal message, and thus be able to react appropriately.

The observance of such general requirements can of course hardly be checked for a plant or supervisory authorities, especially since the requirements are directed at individuals.

When establishing the form of acoustic signals and satisfactory speech communication, it is thus useful to comply with the standards addressed. If these standards are complied with, the minimum conditions for safety and health protection are then met from a technical point of view.

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EN 50099-1: Safety of machinery - Indication, marking and actuation. Part 1: Requirements for visual, auditory and tactile signals.

ISO 11429/EN 981: Ergonomics - System of danger and non-danger signals with sound and light.

EN 457: Safety of machinery - Auditory danger signals - General requirements, design and testing. **ISO 8201**: Acoustics - Audible emergency evacuation signal.

ISO 9921: Ergonomic assessment of speech communication. Part 1: Speech interference level and communication distances for persons with normal hearing capacity in direct communication method.

ISO/TR 4870: Acoustics - The construction and calibration of speech intelligibility.

IEC 268-16: Sound system requirement. Part 16: The objective rating of speech intelligibility in auditoria by RASTI method.

THE EFFECT OF HEARING PROTECTIVE DEVICES ON DIRECTIONAL HEARING IN QUIET AND NOISY SURROUNDINGS

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Abstract

This study compared sound localization with the ears unoccluded and fitted binaurally with either a conventional muff or plug or a level-dependent muff with limited stereophonic amplification. Two groups of 24 normal-hearing listeners, under and over 40 yrs of age, participated. Sound localization was assessed in a semi-reverberant chamber, using a horizontal array of six speakers, positioned 60 deg apart. The stimulus was an 80 dB SPL one-third octave noise band. Two centre frequencies, 500 and 4000 Hz, were tested, so that interference with interaural disparities in time of arrival and intensity, cues to spatial location, could be assessed independently. The experiment was conducted in quiet and in a continuous 65 dB SPL white noise background. One block of 120 trials was presented for each of the sixteen listening conditions. Within a block, the test sound emanated randomly from each of the six speakers on 20 trials. Accuracy was highest in the unoccluded condition and decreased significantly when protectors were worn. For the 500 Hz stimulus, there were no differences among protectors. Front/back but not right/left discrimination was affected. In contrast, for the 4000 Hz stimulus, the prevalence of right/left confusions was similar for the conventional muff and plug but declined significantly with the level-dependent device. Front/back discrimination was poorer with the muffs than the plugs, likely because of the disruption of the intensity/pinna cue. The two types of muff were similar. Aging adversely affected unoccluded performance.

Introduction

Personal hearing protective devices (HPDs) are widely used for the prevention of noise-induced hearing loss. They provide a relatively low-cost, easily implemented alternative to noise reduction at the source, and, thus, have become an important component of industry-based hearing conservation programs. Previous research has demonstrated that the wearing of these devices may induce a communication handicap by interfering with the perception of speech and warning signals. This is particularly true for the user who has already sustained a sensorineural hearing loss (1, 2). The latter group may receive some benefit from level-dependent muffs relative to conventional devices (3). The former type of protector provides minimal attenuation or limited amplification at low sound intensities, depending on the model.

The present experiment was undertaken to assess the effect of HPDs on sound localization in both quiet and noisy surroundings. The work was motivated by the concern that the wearing of muffs or plugs might interfere with the perception of the direction of potential hazard. Most studies reported in the literature have shown that HPDs are detrimental to sound localization in quiet, muffs more so than plugs, possibly because of interference with cues provided by the pinna of the ear (4, 5, 6). A very recent paper

suggests, in contrast, that conventional level-independent earplugs and earmuffs, and level-dependent muffs with dichotic (or stereophonic) amplification will be similar with respect to front/back confusions. Muffs with limited diotic amplification will be severely disruptive (7).

Variables which are known to affect auditory perception and have not been explored within the context of experiments on sound localization with HPDs include the effect of aging without concomitant hearing loss, background and stimulus frequency (3, 8). In order to study the effects of these factors, we tested two groups of 24 normal hearing subjects, under and over the age of 40 years, respectively. Sound localization was studied in quiet and in a background of continuous 65 dB SPL white noise. The test stimuli were one-third octave noise bands, centred at 500 Hz and 4000 Hz, allowing the independent evaluation of the utilization of interaural differences in time of arrival and intensity as cues. The former has been shown to deteriorate with aging (9). Judgements were made first with the ears unoccluded and subsequently fitted binaurally with each of two conventional HPDs (E-A-R foam plugs and E-A-R 3000 earmuffs) and one level-dependent muff with limited stereophonic amplification (Bilsom 2392). The test sound was presented at a level of 80 dB SPL. At that level, the Bilsom 2392 amplifies sounds in the frequency region of 800 Hz to 4000 Hz by about 5 dB.

Method

Subjects

Subjects in the younger and older groups ranged from 18-38 yrs. and 41-58 yrs., respectively. Screening tests were conducted to ensure that hearing thresholds were less than 20 dB SPL bilaterally from 500 Hz to 4000 Hz. All the subjects were paid volunteers. None had previously participated in a sound localization study.

Apparatus

The experiment was conducted in a semi-reverberant chamber that met the ANSI standard for hearing protection testing (10). Six speakers were positioned 60 deg apart in the horizontal plane at ear level and at a distance of 1 m from the subject's centre head position, at azimuth angles of 30, 90, 150, 210, 270 and 330 deg. Details of the apparatus are given in Giguère and Abel (8, 11). Subjects responded using a specially designed lap top response box with a circular array of microswitches, in the same configuration as the speaker array.

Procedure

One block of 120 trials was presented for each of the sixteen listening conditions (4 ear conditions by 2 backgrounds by 2 test frequencies). Within a block, the test sound was presented from each speaker on 20 trials, in randomized sets of six speakers. The duration of the test sound was 300 ms, including a 50 ms rise/decay time.

A forced-choice speaker identification paradigm was used. Each trial began with a 500 ms warning light on the response box, followed by a 500 ms delay, and then the

presentation of the test sound. Subjects were instructed to fixate a straight-ahead visual target each time the warning light appeared and to keep the head steady during the presentation of the stimulus. A maximum of 5 s was then given to choose the response key corresponding to the speaker that had emitted the stimulus. No feedback about the correctness of the judgement was given. Familiarization trials were included at the start of each condition.

Results

Right/Left Discrimination

Figure 1 shows the ability to discriminate between right (30, 90 and 150 deg) and left (210, 270 and 330 deg) speakers, regardless of azimuth. The mean percentage of correct right/left judgements is plotted against the ear condition (UN: unoccluded; PL: E-A-R plug; MI: E-A-R 3000 muff; MD: Bilsom 2392 muff). The results for the two groups are shown separately in the two panels. Within each panel, the outcomes are given for each of the four combinations of stimulus frequency and background. For the 500 Hz stimulus, right/left discrimination was close to 100% in both groups, regardless of the ear condition. In contrast, at 4000 Hz, the wearing of conventional plugs and muffs resulted in a significant decrement of 15%, and the wearing of level-dependent muffs in a significant decrement of 30%, relative to unoccluded listening. The pattern suggests that the interaural intensity cue was disrupted -- equally for the conventional muff and plug. The relatively poor result for the level-dependent HPD is in contrast to a previous report. The presence of background noise resulted in consistently poorer performance of 1-2% in the younger group but no difference in the older group. A nested analysis of variance confirmed that age was not a significant main effect.

Front/Back Discrimination

In Figure 2, the mean percentage of correct front (30 and 330 deg)/back (150 and 210 deg) judgements is plotted as a function of the ear condition for the two groups taken separately. Except for 500 Hz in noise, discrimination was significantly better with the ears unoccluded than protected. With protectors, there was little change due to the type of device for the 500 Hz stimulus, and the result was about 40% correct. For the 4000 Hz stimulus, performance was significantly better with the plugs and with either of the muffs, and the muffs were fairly similar. In the unoccluded or earplug conditions, front/back discrimination was better with the 4000 Hz stimulus than with the 500 Hz stimulus. When the muffs were worn, there was virtually no difference in outcome for the two frequencies, likely because any advantage due to the pinna at high frequencies was disrupted. Younger subjects achieved higher discrimination scores by about 10% for both test stimuli in the unoccluded, quiet condition. Older subjects, however, had significant advantage with the level-dependent muffs for the 500 Hz in noise condition.

Response Latencies

The mean of median response times obtained on the correct (CRT) and incorrect (IRT) trials for each condition are presented in Figure 3. There were no significant differences in the mean response time due to age, nor in the variance. Incorrect responses

took longer to make than correct responses. Except for the unoccluded in quiet condition, the difference was less than 100 ms. Within each group, the more difficult the condition, the shorter the response time. The response time was shorter for protected compared with unoccluded listening, for the noisy compared with the quiet background and for the 500 Hz compared to the 4000 Hz stimulus. This suggests that there were fewer perceived alternative responses to choose among, the more difficult the condition.

Discussion

In the preliminary analysis of the data presented above, we focused on right/left and front/back discrimination. Using this strategy, we hoped to find a rough picture of the kinds of confusions that would result from the wearing of various types of HPDs. Analyses are currently underway of detailed error patterns associated with each of the six azimuths in each experimental condition.

The results confirmed the previously reported finding that normal aging, without concomitant hearing loss, affects unoccluded sound localization. An unexpected outcome was the beneficial effect of the Bilsom 2392 muff for 500 Hz in noise in the older group, possibly due to an improvement in the signal-to-noise ratio. Within each age group, there was a clear cut interaction between stimulus frequency and hearing protector in determining the outcome.

In the unoccluded condition, right/left discrimination was close to 100% for both stimulus frequencies. Front/back discrimination was better at 4000 Hz, in line with previous findings (8). For 500 Hz, the wearing of hearing protective devices did not appreciably affect the discrimination of right from left speakers. There was a 60% decline for front/back discrimination. This outcome was the same for all three devices. For the *4000 Hz stimulus, right/left discrimination* deteriorated with each of the HPDs, but particularly when the muff with limited stereophonic amplification was worn. The conventional muff and plug did not differ. In contrast, for front/back discrimination, listening with the plugs afforded an advantage over the two muffs which were indistinguishable. For neither frequency did background noise have a substantial effect.

The general outcome that HPDs affect sound localization in normal-hearing subjects is in line with published reports. The effect of stimulus frequency has not received much previous consideration. We found that it was localization of the 4000 Hz stimulus that was differentially affected by the various devices tested. The conventional muff and plug were fairly similar for right/left discrimination, suggesting that they disrupted the interaural intensity cue in the same manner. Limited stereophonic amplification played havoc with this cue. With respect to front/back discrimination, we surmise that the protectors interfered with the pinna cue. This is supported by the substantially greater decrements in performance for the muffs relative to the plug. Stereophonic amplification was no more disruptive than conventional attenuation.

These results support the conclusion that where perception of the direction of hazard is an important consideration, both the frequency of the hazardous sound and the nature of the perceptual confusion that would be most hazardous must be taken into account in selecting a hearing protective device, even for normal listeners.

Acknowledgment

The author is indebted to Ms. Valerie H.T. Hay for assistance in the testing of subjects and analysis of results. This research was supported in part by a Research Scientist Award from the Saul A. Silverman Family Foundation

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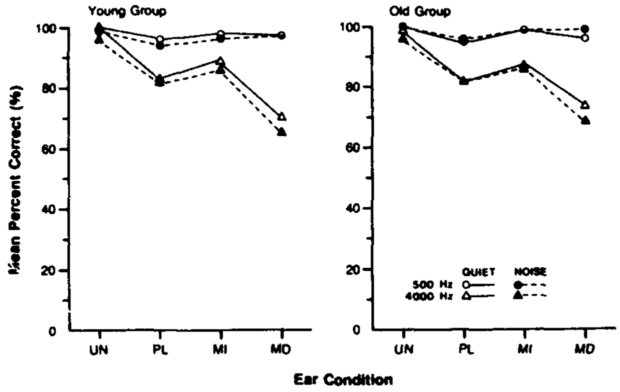

Fig. 1 The discrimination of right and left speakers as a function of ear condition (UN: unoccluded, PL: E-A-R plugs, MI: E-A-R 3000 earmuffs, and MD: Bilsom 2392 earmuffs). The parameters are stimulus frequency, background and age.

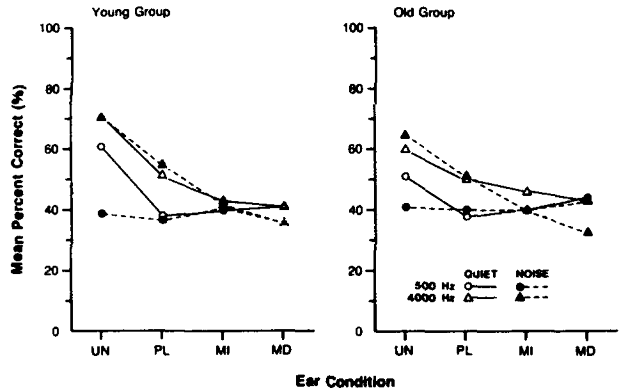

Fig. 2 The discrimination of front and back speakers, as a function of ear condition. As above.

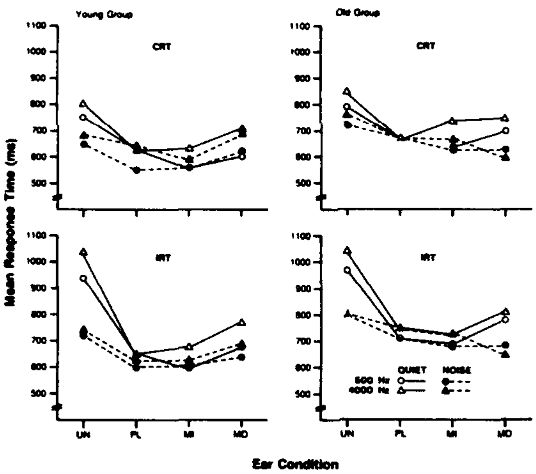

Fig. 3 Correct (CRT) and incorrect (IRT) response times as a function of ear condition. As above.

AUDITORY WARNING DESIGN

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It is important both that auditory warnings are audible, and that their meanings can be identified. In practice, the meaning of an auditory warning is not always clear. It is possible, however, to convey an appropriate level of urgency through the warning itself by the way in which the acoustic features of the warning are manipulated. A series of experiments are described in which the perceived urgency of a set of acoustic stimuli are scaled using an application of Steven's Power Law. Urgency exponents for stimulus speed, frequency, repetition and inharmonicity were derived, and these were used to predict equivalent levels and equivalent changes in urgency across parameters. The predicted and obtained urgency order were highly significant, showing that subjective responses to urgency are predictable and that the effects can be quantified. Regression showed that despite the stimuli being equalised beforehand, stimulus frequency, which produces a relative low urgency exponent, exerts a greater influence on the overall urgency of the stimulus. A number of reasons for this are proposed.

Introduction

There are two primary and quite distinct requirements that must be met in the design of an auditory warning; the first is that it can be heard above the noise background and the second is that, on being heard, the listener knows what the warning means and is therefore in a position to at least attempt to rectify the problem. This paper specifically addresses one potentially important aspect of this latter requirement.

The fundamental problem of the audibility of warnings has been addressed by a number of researchers who have derived guidelines and computer models allowing the prediction of masked threshold over a wide range of frequencies, based on models of the auditory filter. One such set of guidelines has been developed by Patterson (1982) aimed primarily at fixed-wing aircraft but suitable for most noise environments in which the noise level is fairly fixed. This has been implemented in, for example, the design and eventual commission of a set of warnings for military helicopters (Lower et al, 1986). Another slightly different model has been developed by Laroche et al (1991) primarily aimed at more open working environments such as factories, for which there now exists a commercially available software suite. This has been used in experimental work looking at the potential for masking of a large set of co-existing warnings by one another in the intensive care wards and operating theatres (Momtahan et al, in press). Thus it is quite possible to predict the appropriate loudness level for auditory warnings in a range of work environments although specific problems such as the effects of the wearing of ear defenders, a fluctuating background level and so on remain something of a problem.

The second primary requirement, that the recipient of an auditory warning is able to ascertain the meaning of a warning once it is heard, presents us with a set of psychological, rather than psychoacoustic, problems. In the ideal case, the recipient has been carefully trained in the meaning of a small but carefully chosen set of auditory warnings. In practice, it is often the case that no, or very little, training has been given and the set of warnings is often very large and confusing because warnings have been added to the work environment on an ad hoc basis. Momtahan et al's study shows that, aside from the problem that many warnings can potentially mask one another if they happen to sound at approximately the same time, professional medical staff are unable to identify about half of the nearly fifty warnings that they might hear during their normal work. This is not surprising given the number of warnings possible, and the acoustic qualities of the sounds typically used.

There are a number of ways in which this problem, which arises again and again in high-workload environments in particular (Rood et al, 1985; Thorning & Ablett, 1985), could be at least partially solved. The simplest, which would be to cut down the number of warnings typically occurring in the environment, is hard to achieve in practice because of the fear of increasing the chances of crucial events not being signalled by warnings. One alternative solution is to capitalise upon any associations that the recipient is able to make between the warning sound and the situation which it is signalling. There are a number of ways in which these potential associations can be explored.

One way in which these associations can be capitalised upon is to explore the established, learned associations between traditional warning sounds such as bells, horns and sirens as has been done by Lazarus & Hoge (1986). This research shows, for example, that sirens are particularly associated with danger situations and that other associations, perhaps not quite as strong as this one, also exist.

Another, complementary approach to this problem is to capitalise upon rather more basic, and perhaps less learned, rather more 'instinctive' reactions to sound. That is, to take advantage of associations between sounds and psychological constructs which are already in effect in place. In the case of auditory warnings, and important construct is that of urgency. The implicit urgency of an auditory warning, it can be argued, will be conveyed to the listener whether he or she knows the meaning, because it is one of several attributes that will be conveyed by the sound itself. It is well known that urgency, amongst other things, can be conveyed by the way in which sound parameters are combined otherwise there would be no place for film music, which there clearly is. An auditory warning which is psychoacoustically urgent by virtue of the way the sound is constructed could convey this urgency to the recipient even if the meaning of the warning is not known. In practice the relationship between the psychoacoustic urgency of the warning and the situational urgency of the problem being signalled is poor, even non-existent. Warnings which are psychoacoustically urgent are sometimes used to convey non-critical situations, whilst vital life-preserving equipment such as ventilators can be associated with non-urgent warnings (Meredith & Edworthy, in press). Momtahan et al (in press) have shown this experimentally, and have referred to the process of matching warnings to situations on this basis as 'urgency mapping'. In this paper I will describe a set of experiments which demonstrate the robustness of the psychological attribute of urgency in sound, which can be used to make very specific predictions about the relative urgencies of a set of sounds and can therefore directly address the issue or urgency mapping.

Experimental studies

In a number of studies we have attempted to relate the perceived urgency, an assumed subjective attribute of a single sound parameter or a combination of sound parameters, to objective values and changes in those parameters. Steven's Power Law (1957) has been used in this work, and a range of methods for scaling this have been tested and evaluated (Hellier et al, in press). The perceived urgency of a sound is a second order attribute in that the feature that is scaled, the urgency, is a consequence of changes in physical parameters such as the length of a stimulus, its frequency, its speed and so on. Subjects are not actually scaling this attribute, which would be first order scaling, but are scaling a secondary feature of this attribute. A similar technique has been used by Hellman and Zwicker (1990) and Kuwano & Namba (1990) in the measurement of the annoyance levels of noise.

In an earlier series of studies (Edworthy et al, 1991) the effects of a range of spectral, temporal and melodic features on the perceived urgency of sound were explored. Patterson's guidelines (1982) were used as the basis for the development of the sounds, because they produce the potential for easy manipulation of a large range of acoustic parameters. Such manipulation is not as possible with traditional warnings such as bells and horns, but there is no reason why the results of these studies should not also apply to such warnings. In summary, these experiments show that features including harmonic content, onset and offset envelope, frequency, speed, repetitions, pitch range and other potential warning parameters affect the subjective urgency of acoustic stimuli in a reliable and systematic way. For example, a warning which is constructed of several small pulses of sound (as recommended by Patterson, 1982) can be readily manipulated in terms of its speed because the pulse-to-pulse interval can be increased or decreased. Our results show that increases in speed reliably and consistently produce increases in urgency judgment, and decreases in speed have the opposite effect. Such effects were observed for other parameters to a greater or lesser degree.

The method of multiple comparisons was used for this work, which shows only the direction, and not the magnitude, of individual effects. The results indicated that some parameters such as warning speed had greater effects on perceived urgency than other such as harmonic content. In order to quantify this in a more precise way, we carried out a large series of experiments in which Steven's Power Law was used to quantify the relationship between objective changes in parameters and subjective changes in urgency.

It was first established that the most reliable methods for scaling urgency were magnitude estimation and line length (Hellier et al, in press). In a further series of experiments, the relationship between four potentially important acoustic parameters in warning design - inharmonicity, speed, frequency and repetition - was charted by asking subjects to draw a line to match the urgency of seven stimuli covering a range of values for each of the four parameters. These four parameters were chosen for two main reasons; first, they appeared to have a significant effect on urgency in the earlier studies, and secondly they are readily quantifiable, a necessary attribute if Steven's Power Law is to be applied. Speed was quantified by measuring the number of individual pulses per second; frequency was measured in hertz; repetition was measured simply in terms of the number of times that a small unit of sound repeated; and inharmonicity was measured in terms of the number of inharmonic components, up to a maximum of 14, in the stimulus. The 28 stimulus levels are shown in Table 1.

Stimulus	Speed	Frequency	Repetition	Inharmonicity
1	3.69	210	2	0
2	4.98	250	2.5	1
3	5.71	260	3	3
4	7.87	320	3.5	5
5	9.63	440	4	7
6	10.0	500	5	9
7	11.93	680	6	14

Table 1: Stimulus levels used in initial scaling experiments

The results of this experiment replicated and extended the earlier findings. As before, each parameter was found to have a consistent effect on the direction of the urgency judgement, and in addition an exponent for each parameter, relating subjective changes in urgency to objective changes in that parameter, was derived. The exponents are shown in Table 2.

Parameter	Exponent
Speed	1.35
Frequency	0.38
Repetition	0.50
Inharmonicity	0.12

Table 2: Urgency exponents for four acoustic parameters

Thus the larger the exponent, the greater the change in urgency produced by a unit change in that parameter. A unit change (say 50%) in the speed of a stimulus would have a much greater effect on the urgency of a stimulus than, say, a 50% change in inharmonicity. These exponents are therefore of some practical use in terms of predicting how the urgency of a stimulus could be changed by varying acoustic parameters which may be available in its structure.

If the exponents are robust, they can be used to make specific predictions about the relative urgencies of warning-like stimuli. Theoretically the speed, the frequency, the number of repetitions

and the degree of inharmonicity corresponding to a particular subjective judgement (in this case, a particular line length) should be equally urgent regardless of the parameter through which that urgency is conveyed. This hypothesis was tested in a further series of experiments.

Three levels of urgency (line length) were chosen, designated as 'Low' (corresponding to a line length of 85mm), 'Medium' (113mm) and 'High' (150mm). The objective values of speed, frequency and repetition rate corresponding to these three line lengths were calculated using the Power Law equation using the exponents previously derived. The levels of these three stimuli are shown in Table 3.

Urgency level	Speed	Frequency	Repetition
Low	7.33	74	1
Medium	9.22	168	2
High	11.65	378	3.5

Table 3: Parameter values corresponding to three specific levels of urgency

Inharmonicity was excluded from the study because the low value of the exponent rendered it impossible to produce any great variation in urgency within the practical limits set by the stimulus construction.

A set of 27 stimuli was constructed from the three levels of each of the three parameters. Thus one stimulus consisted of the high level of all three parameters; three stimuli consisted of the high level of one of the parameters and the medium level of the other two, and so on down to the twenty-seventh stimulus, which consisted of the low levels of each of the three parameters. The urgency order of this set of stimuli was predicted on the basis that the stimulus consisting of high levels of all three parameters would be judged to be the most urgent; the next most urgent would be the three parameters with one high and two medium levels or urgency; the next (all equal) would be those consisting of either two high and one low, or one high and two medium levels of urgency and so on, down to the least urgent, the stimulus with the three low levels of urgency. A magnitude estimation procedure rather than a line-length task was used in this experiment as the judgments required were very fine in nature.

A Spearman's rank correlation between expected and obtained order revealed a correlation of 0.9 ($p < .01$). A few of the stimuli were ranked other than in the order predicted, and preliminary inspection of the data revealed that the value of the frequency parameter had a greater effect than the others. That is, the frequency component appeared to be exerting a greater influence on the overall judgement of urgency than the other two, despite the fact the urgency levels had been equalised before the experiment as described above.

A multiple regression on the date revealed that fundamental frequency had a greater effect on the overall judgment of urgency than the other two parameters. The coefficients can be seen in Table 4.

Parameter	Coefficient
Speed	0.037
Frequency	0.189
Repetition	0.059

Table 4: Urgency coefficients for three acoustic parameters

The data was fitted to three reduced regression models in which the parameters were combined in pairs (Neter et al, 1985). This comparison showed that the frequency coefficient was significantly higher than the other two ($p < 0.01$). There was also a smaller difference between the repetition and the speed coefficients ($p < 0.05$). However, the observation that frequency appeared to be exerting a greater influence over urgency judgments was borne out by the comparison of regression coefficients.

Discussion

These experiments show that the subjective, perceived urgency of acoustic stimuli can be scaled and the urgency order of a set of stimuli predicted on the basis of the results of scaling studies. Thus it can be concluded that the subjective response to urgency is a fairly robust and systematic one, and therefore useful in the practical design of auditory warning signals.

Surprisingly, although the stimuli were equalised for urgency levels prior to testing, multiple regression showed that fundamental frequency appeared to exert a greater influence on urgency than the other parameters, even though the exponent for speed, for example, was much greater. There are a number of possible interpretations of this finding, which must for now remain speculative. It might be that this effect is, paradoxically, a result of the smaller exponent derived for fundamental frequency. If equal changes in urgency are generated from the exponents shown in Table 2, then a much larger change will be required in fundamental frequency than in speed, in particular, which has a much larger exponent, in order to produce the same change in perceived urgency. Paradoxically, this may then draw the listener's attention to the frequency because the changes needed to produce changes in urgency are larger, and possibly thus more salient. Thus the effect may be due to the large changes in frequency required. It may therefore be unwise to recommend fundamental frequency as the most effective way of communicating changes in urgency, precisely for this reason. Large changes in urgency produced solely by changes in frequency would quickly result in warnings that would be irritatingly high or low in pitch, and therefore unergonomic. Manipulating urgency through parameter with higher exponents, particularly speed, will be much more practicable in general.

Another possible explanation for this finding is that frequency is a fundamentally different parameter from both speed and repetition. Speed and repetition are prothetic continua (Stevens & Galanter, 1957); changes in both of these parameters produce quantitative changes in the resulting stimulus. Frequency, however, is a metathetic continuum whereby changes in frequency alter the quality, rather than the quantity, of stimulation. Changes in the quality of a stimulus may therefore be more salient to the listener than changes in its quantity, which may account for the effect found. This apparent salience of frequency changes may be more useful in conveying features other than the urgency of a warning signal, particularly in view of the low exponent value. It may be particularly useful for example in the design of monitoring sounds in which slight changes in the status of some physical parameter needs to be conveyed quickly (Edworthy et al, 1992).

Future issues

Given that auditory warnings present the potential for mapping the urgency of the warning to the urgency of the situation being signalled, an important aspect of perceived urgency that has yet to be explored are the behavioural consequences of appropriate urgency mapping. It will be necessary to ascertain whether or not urgency mapping produces more appropriate responses to those warnings. One suggestion that simple urgency mapping improves performance, using voice warnings, comes for Sorkin et al (1988). It is necessary to test whether the same is true for nonverbal auditory warnings.

Another aspect of auditory warning design of equal importance to urgency is confusion; although appropriate urgency mapping might well reduce confusion, it is important to understand the mechanisms underlying confusion between warnings. Patterson (1982) has demonstrated that warnings sharing the same temporal pattern but with otherwise quite different acoustic qualities can be readily confused. This again underlines the importance of temporal information in warning discrimination. We are carrying out a series of experiments in which a sample of current intensive care unit alarms are first learnt, then tested for confusion, and then tested for retention under a variety of workload conditions (Meredith & Edworthy, in press). These experiments show that some warnings are much more resistant to forgetting than others even under high workload conditions. The results also indicate that confusions between warnings which are acoustically quite different from one another can become confused with one another even when they have been previously learned successfully. One possible explanation for this is that the warnings are encoded via verbal description, rather than via the acoustic properties themselves. Thus two warnings might be confused because they are both 'musical', or 'fast'. A critical feature of auditory confusion might therefore be the level of specificity at which the warnings are encoded verbally. This will be a topic for investigation in the future.

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MODERN TECHNIQUES FOR IMPROVING SPEECH INTELLIGIBILITY IN NOISY ENVIRONMENTS

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This paper reviews methods for estimating speech intelligibility, and discusses the latest technology for loudspeaker and/or microphone arrays for improving speech intelligibility.
Speech intelligibility (SI) in reverberant and noisy conditions is a primary objective for acoustic engineering. Moreover, designing an acoustic space which has both high intelligibility and full spaciousness is a primary objective for concert hall acoustics.

Miyata and Houtgast (Proc. of Eurospeech 91, 289-292) proposed a new method that uses an exponentially decaying time window function for determining the MTF in a reverberant space. Intelligibility tests using a variety of computer-generated squared-impulse responses confirm that their method is better than the ordinary MTF method.

When speech is recorded with a microphone in a room, the sounds produced by the speaker may reach the microphone by many separate paths. To preserve the SI, we must maintain either a high energy ratio between the sounds received directly from the speaker and the time-delayed reflections (D/R) or a high energy ratio between the direct sound and the room noise (D/N). Nomura, Miyata, and Houtgast (Acustica 77, 253-261) described the theoretical increase in D/R and/or D/N that can be obtained by using microphone arrays. They used calculations based on the statistical properties of a diffuse sound field. Their technique is useful for improving the SI in a reverberant and/or noisy room. Another approach was taken by Kaneda and Ohga (Proc. IEEE, ASSP 34, 1391-1400). They developed a small-sized microphone array using a sophisticated adaptation algorithm. Their array technique is also effective at reducing "directional" noise source signals.

The importance of the initial portion of the reverberant energy decay curve has been pointed out for subjective effects in non-exponential decay fields (J. A. S. A. 58, 853-857). Nomura, Miyata, and Houtgast (Acustica 69, 151-155) performed SI tests in a reverberation room with an absorbent floor where non-exponential decay fields occur. A highly absorbent floor can greatly improve the SI, even though the total reverberation time is still long. It should therefore be possible to design an acoustic space can be designed to have both high intelligibility and full spaciousness.

The MTF for SI is based on the monaural criterion of sound fields. Normal human listeners, however, hear speech signals under "dichotic" listening conditions. Therefore, we can expect the SI to be increased by binaural listening in sound fields. Howere, this is, a complicated issue and is still under investigation (Miyata, Nomura, and Houtgast, Acustica 73, 200-207; Nakajima and Ando, J. A. S. A. 90).

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This paper reviews methods for estimating speech intelligibility (SI), and discusses the latest technology for loudspeaker and/or microphone arrays to improve SI. Achieving good SI under reverberant and noisy conditions is a primary objective in acoustic engineering. MTF is now very commonly used to estimate SI, however, a new weighted MTF using a time-window function is shown to offer more accurate estimation. Also, *D/R* and/or *D/N* can be increased by using loudspeaker and/or microphone arrays and adjusting time delays and gain factors. The importance of the initial energy decay rate for SI, and the SI under dichotic listening conditions are also briefly mentioned, while the robustness of the selective-listening-based "best ear" hypothesis is demonstrated. Finally, a signal-processing scheme for dereverberation using cepstra is outlined.

I. A New Definition of Weighted MTF of a Reverberant Space

The Modulation Transfer Function (MTF) by Houtgast and et al[1] was introduced for assessing the effect of an enclosure on SI . Miyata and Houtgast[2] proposed a new method that uses an exponentially decaying time window function for determining the MTF in a reverberant space. It gives the weighted MTF, expressed by

$$m_W(F) = \frac{\left| \int_0^\infty w(t)\, h^2(t) \exp(-2\pi j F t)\, dt \right|}{\int_0^\infty w(t)\, h^2(t)\, dt}, \quad \text{where } W(t) = \exp(-t/\tau) \qquad (1)$$

and τ is the window parameter, for example, 0.2 ms. Both weighted and conventional RASTI can be derived from the weighted MTF. SI tests using a variety of computer-generated squared-impulse responses (echogram patterns) confirm that this method's weighted RASTIs are better than the ordinary MTF-method RASTIs (Fig.1). Miyata and Houtgast[2] experimentally confirmed that their weighted method is a SI good predictor for reverberant sound fields, at least for the limited range of models tested. More investigation is required to confirm its

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applicability to hearing and SI technology.

II Sound Reinforcement for SI

A. Loudspeaker Arrays for Improving SI

SI increases in a reverberant space as the ratio of direct to reverberant sound energy (*D/R*) increases. Nomura et al.[3,4] investigated ways to increase *D/R* and consequently proposed a loudspeaker (or microphone) array design that improves SI in a reverberant space.

1. *D/R* at a listening position in a Reverberant Space

The energy ratio of direct sound from the source to the reverberant energy (*D/R*) at a listening position decreases in inverse proportion to the squared distance from the source in a diffuse field. If a pair of identical sources radiates the same signal, the direct sounds of the two sources are completely coherent at all listening positions located equidistant from the two sources. Reverberant sounds are uncorrelated, however, if the distance between the pair of sources is larger than the half wavelength of the source frequency[5]. Thus, with two "uncorrelated sources" for the reverberant sounds, the *D/R* becomes twice as high as that for a single source. For an array of sound sources on a circle of radius r, the *D/R* at the center of the circle becomes N_{uc} times higher than that for a single source, where N_{uc} denotes the number of uncorrelated sources on the circle. A circular array increases the *D/R* at the center of the circle in a reverberant field.

2. Loudspeaker Linear Array in a Reverberant Field

A linear array can also improve SI. Figure 2 is a schematic diagram of a linear loudspeaker array. The delay times are set to specific values so as to add direct sounds in phase at the focal point. The amplifier gain for each loudspeaker is adjusted to $a_i = r_0/r_i$ in order to obtain the theoretical maximum increase in *D/R* of about 5 dB at the focal point in a reverberant sound field, assuming point-source characteristics. Figure 3 shows a plot of the measured RASTI vs normalized distance, when $r_0/r_C = 3.0$, and r_C denotes the critical distance at which *D/R* becomes unity. In this case, $r_C = 0.27$ m at 500 Hz. This figure illustrates that the maximum RASTI is obtained at the focal point, and that it is nearly 70% higher than for a single loudspeaker placed in front of the focal point. These results agree well with the theoretical estimation of a 5-dB increase in the *D/R* for a linear array over that for a single source. Moreover, the RASTI for a linear loudspeaker array is better than that for a single loudspeaker in a region that extends over several times the critical distance in a reverberant field.

B. Microphone Arrays for Improving Speech Intelligibility

When speech is recorded with a microphone in a room, the sounds produced by the speaker may reach the microphone by many separate paths. To preserve the intelligibility of speech, we must at least maintain either a high energy ratio between the sounds received directly from the speaker and the time-delayed reflections (*D/R*) or a high energy ratio between the direct sound and the room noise (*D/N*). Nomura, et al.[6] also described the theoretical increase in *D/R* and/or *D/N* that can be obtained by using microphone arrays with time delays and gain adjustments. They used calculations based on the statistical properties of a diffuse sound field in a manner quite similar to that for the loudspeaker arrays described above.

Another approach was taken by Kaneda and Ohga[7]. They developed a compact microphone array for noise reduction using a sophisticated adaptation algorithm. Their array technique is also quite effective for in reducing "directional" noise source signals.

III. SI in a Non-exponentially Reverberant Decay Field

Ensuring adequate SI in a reverberant space is a primary objective of sound field control. Meanwhile, ensuring both high SI and optimum spaciousness is a primary objective in designing concert halls. Reverberant sounds in a room normally decay exponentially over time; however, non-exponential decay is also possible[8]. The importance of the initial portion of the reverberant energy decay curve has been pointed out for the subjective effects in non-exponential decay fields[9]. Nomura, et al.[10] performed SI tests in a reverberation room, where the floor was completely covered with sound-absorbing materials, to compare SI scores with those for exponential decay fields. SI scores can be estimated from the MTF by using the reverberation time of the initial portion of the reverberation energy decay curve.

A. Non-Exponential Reverberant Energy Decay Fields

Figure 4 shows a rectangular reverberation room with the floor completely covered with absorbing materials. Figure 5 shows an example of a decay curve at 500 Hz (1/1 octave band center frequency) for the room. This shows that the decay function is not a simple exponential curve, but rather is composed mainly of two types of exponential decay. We can therefore find two kinds of reverberation times T_R [8]. For the initial portion of the decay curve, T_{R1} is about 2.5 s; for the later part of the decay curve, T_{R2} is about 10.5 s.

B. SI scores, RASTI, and Reverberation Time

The SI scores shown in Figs 6a and 6b are much higher for the absorbing floor than for the empty room, even when the talker-to-listener distance increases. These results suggest that the T_{R1} from the initial portion of the decay curve governs SI. These figures

also show the calculated and measured RASTI. The RASTI for the absorbing condition follows the theoretical curve obtained using T_{R1}, demonstrating that SI scores are strongly related to T_{R1}.

SI scores with non-exponential decay curves therefore depend on the reverberation time in the initial part of the decay curve. A highly absorbent floor can greatly improve SI, although the total reverberation time is still long. We can thus expect that an acoustic space can be designed to have both high intelligibility and optimum spaciousness.

IV. Binaural Gain for SI

MTF for determining SI is based on the monaural conditions in sound fields. Normal human listeners, however, hear speech signals under "dichotic" listening conditions. We can generally expect therefore that SI can be increased by binaural listening in sound fields. Miyata[11] and Nakajima et al.[12] suggested that SI scores can be increased by changing the interaural cross-correlation of reverberant sound fields. This is, however, a complicated issue and is still under investigation.

An alternative approach is Miyata, Nomura, and Houtgast's[13,14] suggested "best ear hypothesis," based on selective listening. Figure 7 shows the robustness of this approach for SI of noisy signals. Under the experimental conditions (Fig. 7a), a listener hears the mixed noise and speech signal with his (or her) left ear only, or the mixed signal in the left ear and noise only in the right ear. The level of the right ear noise is changed independent of the left ear noise in order to check the selective listening hypothesis for the left ear. That is, if this hypothesis is true, SI scores do not decrease even when right ear noise is added. The results plotted in Fig. 7b demonstrate the robustness of the best ear hypothesis for this case.

V. Cepstrum Dereverberation of Speech

Dereverberation by inverse filtering is a fundamental technology for improving SI in a reverberant space. If we know the complete transfer function, it is theoretically possible to recover the input signal from the output reverberant signal by inverse processing; in most actual situations, however, it is almost impossible to obtain the perfect transfer function data. Therefore several trials[15,16] have been done without transfer function data, however, they are still pending. Tohyama et al.[17] also recently reported an approach using complex cepstrum windowing where high time components are cut out in the cepstrum region, since those high time components are mainly due to the reverberant sounds. Figure 8 shows the steps of their speech recovery process. Figure 9 shows the original, reverberant, and recovered speech waveforms recorded in a reverberant space. The effects of dereverberation are not pronounced, but Fig.10 demonstrates that the reverberant decay components are slightly reduced by repeating the dereverberation process, which varies the time-window length.

Summary

We reviewed some of the recent progress in signal enhancement technology in reverberant and/or noisy environments: A new weighted MTF reduces SI prediction errors in reverberant spaces. Microphone and/or loudspeaker arrays yield higher SI than that for conventional arrangements. The steep initial reverberant energy decay rate makes it possible to design a good acoustic space. The best ear hypothesis is robust for noisy conditions. Finally, a cepstrum technique is promising for dereverberation. Human (and machine) communication using speech and/or sounds is essential for multi-media communication. Improving the quality of communications and also achieving virtual-reality-quality communications is a formidable problem under real conditions. Therefore, research and development efforts in acoustic signal processing and human hearing are also quite important for future communication systems.

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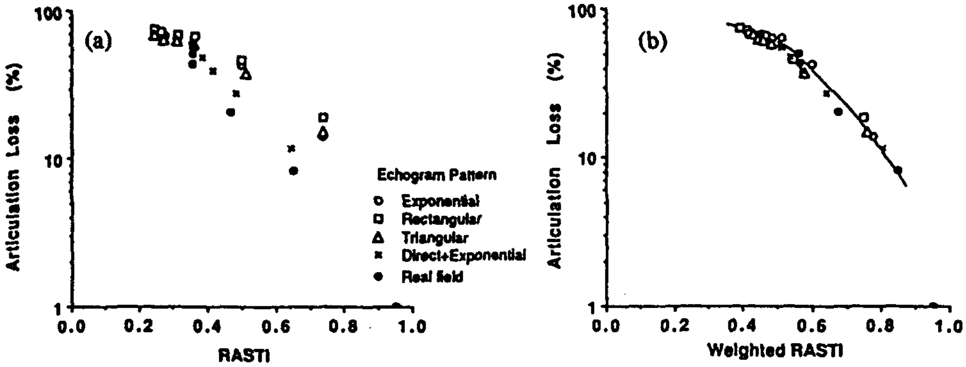


Fig. 1 Articulation Loss vs RASTI and weighted RASTI using computer-generated-echogram patterns

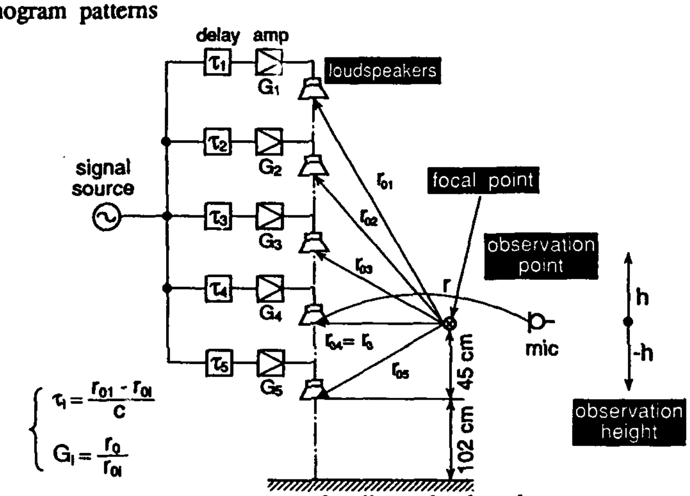


Fig. 2 Schematic diagram of a linear loudspeaker array

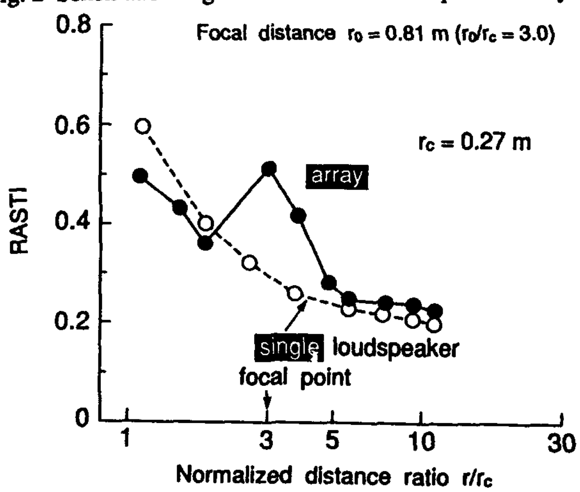
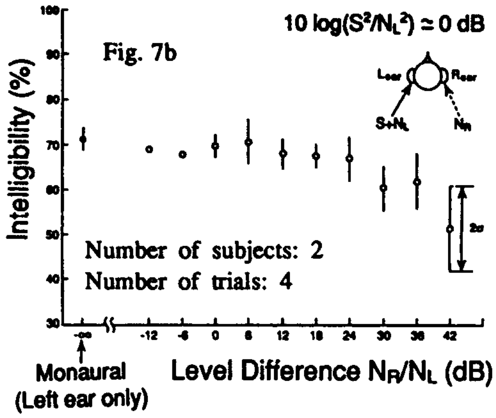


Fig. 3 RASTI vs normalized distance using the linear loudspeaker array



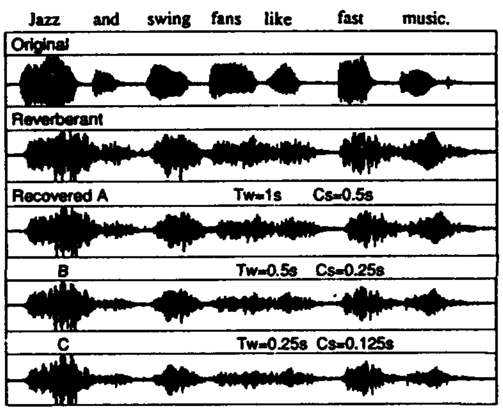


Fig. 8 Recovery process of cepstrum dereverberation

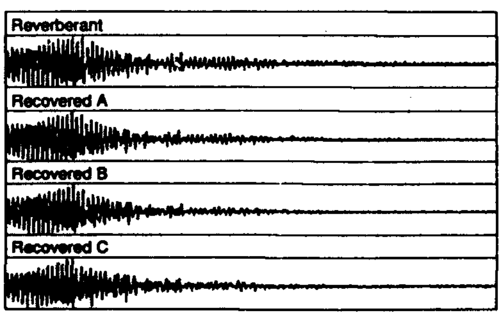


Fig. 9 Original, reverberant and recovered speech waveforms; Tw: window-length(s), Cs: cepstrum cutoff time (s)

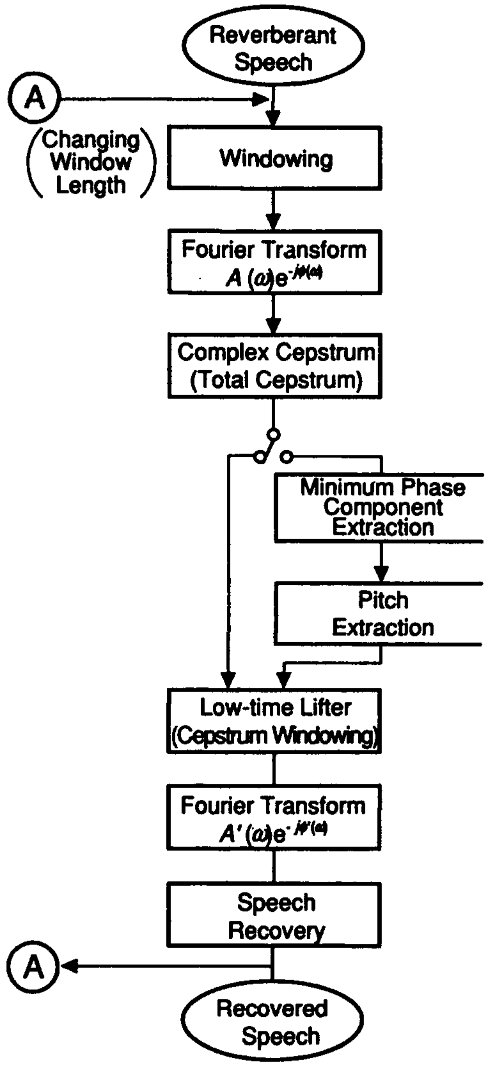


Fig. 10 Dereverberation effect on speech tail

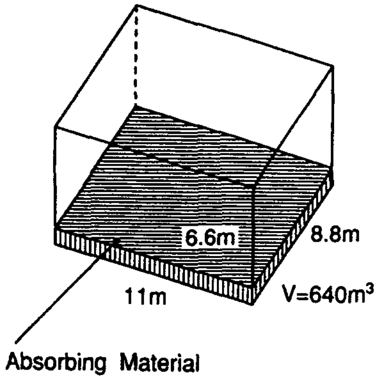


Fig. 4 Rectangular reverberant room with absorbing floor

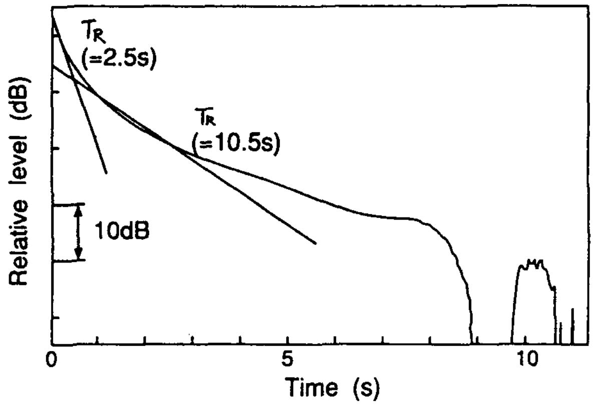


Fig. 5 Non-exponential decay curve in the rectangular reverberant room

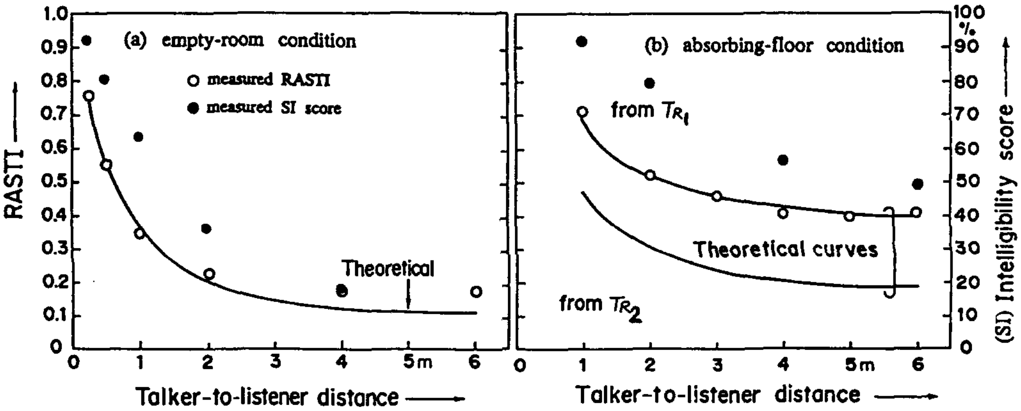


Fig. 6 RASTI and SI vs talker-to-listener distance in the rectangular reverberant room

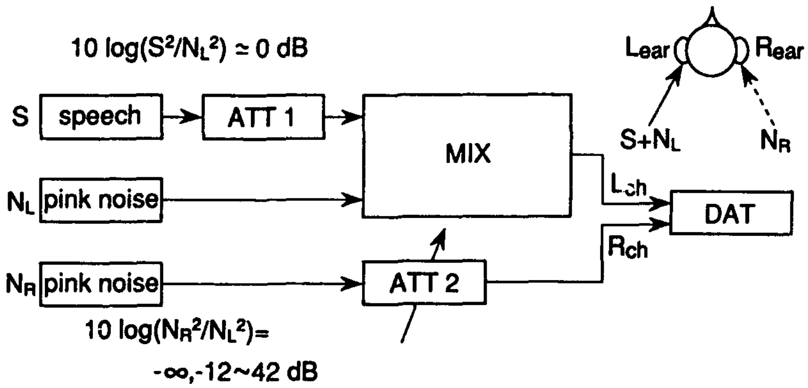


Fig. 7 Robustness of the listening-based best ear hypothesis
(a) experimental conditions, (b) SI vs interaural noise level difference

Summary of Team 2, by Tammo Houtgast

I would like to make a few points, both looking back and looking ahead. Considering the first viewgraph used in my Introduction of the Team-2 Session, that typically reflects an engineering approach: There is a source (speech) and a receiver (listener), and something in-between, and the various factors included in this chain of communication are identified and treated from a technical point of view. For the purpose of the present overview, I like to slightly change the perspective, and indicate the possible implications of our field within the context of Noise as a Public Health Problem. The viewgraph presented here provides a framework for that purpose: The topic noise-and-communication placed within the context of Noise as a Public Health Problem.

Viewgraph 1. The Team-2 topic within the context of Noise as a Public Health Problem.

General context: NOISE AS A PUBLIC HEALTH PROBLEM

Team-2 topic: Noise and Communication

OCCUPATIONAL

* Safety:	Warnings Speech Messages Situational awareness
* Performance:	Stress, fatigue Concentration

Action needed:
To make the available knowledge broadly accessible in practical terms.

NON-OCCUPATIONAL

* Wellbeing:	Communication interference Hear "all" relevant sounds

Action needed:
Research on the effects of noise on auditory wellbeing.

The viewgraph identifies two fields. First the field of occupational problems in the work situation, in which the main factors are safety and performance. Safety is related to the detection and identification of warning signals or spoken messages,

and also to the broader concept of being aware of the acoustical surround, for instance hearing the sounds of the machinery and the equipment. Concerning the second factor, performance, I think of a teacher and pupils in a classroom where high noise levels interfering with communication may cause a stress problem, both on the side of the teacher and the pupils. One may think also of other examples were good speech communication is essential (meeting rooms, offices) and were noise may cause stress, annoyance and discomfort. Looking back to the papers presented, both the invited papers in the Session and the contributed papers, most of these refer to this field of occupational problems. I think that we have a lot of knowledge already, fragmentated in different parts and disciplines. What we need in this field is transfer of knowledge: To integrate the available knowledge and make it accessible, in practical terms, in the context of Public Health.

The other field refers to the non-occupational situation, and the main factor indicated in the viewgraph is *wellbeing*. Noise annoyance in general is a much debated concept, including many ingredients, and in this respect I want to put forward the concept of auditory wellbeing in the home situation. This does not only refer to an undisturbed speech communication, but to hearing in general: hearing that someone enters your back door, hearing the cry of the baby upstairs, hearing all kinds of sounds which keeps you aware of your acoustical surround. The noise interference with this type of auditory wellbeing certainly refers to the Public Health area, and I think our knowledge here is still limited. Let me give an example. If one wants to set limits for indoor noise levels, this can be based on the interference with speech communication: Given a speech level of, say, 60 dB at one meter in front of a talker, one will find for a typical living room situation that the performance in terms of word score will start to drop for noise levels in excess of 45 to 50 dB, and that defines the noise limit. But in the broader sense of auditory wellbeing, this approach is too simple. Being aware of the acoustical surround includes more than the undisturbed understanding of speech. What we need here is an inventory of the types of sound which constitute the acoustical surround, and at what levels noise starts to interfere with the detection and discrimination of these sounds. This will often include weak sounds as well, and I think you will get close to 30-35 dB as the critical indoor noise level in relation to auditory wellbeing, but this should be substantiated with actual subjective measurements, of course.

So, looking ahead and giving a message to Team 2, which I am now leaving as Chairman, I would say that in the field of occupational noise, the emphasize should be on knowledge transfer: To make the existing knowledge in the various fields broadly accessible, in practical terms. For the non-occupational situation, I think the general concept of auditory wellbeing requires more research: To take stock of all relevant sounds around us in a typical living situation, and to study the effect of noise interference for these sounds.

Résumé de la session 2
Bruit et intelligibilité de la communication

Tammo Houtgast - TNO, Soesterberg, Pays-Bas

J'aimerais faire quelques remarques, sur le passé et sur l'avenir. En examinant le premier graphique utilisé dans mon introduction de la session de l'équipe 2, qui typiquement démontre une approche de l'ingénieur : il y a une source (le discours) et un récepteur (l'auditeur), et quelque chose entre les deux, et les différents facteurs compris dans cette chaîne de communication sont identifiés et traités sur un point de vue technique. Au sujet de la vue d'ensemble actuelle, j'aime changer légèrement la perspective, et indiquer les implications possibles de notre domaine dans le contexte de Bruit comme Problème de Santé Publique. Le graphique présenté ici fournit une structure dans ce but : le sujet bruit et communication placé dans le contexte de Bruit comme Problème de Santé Publique.

Graphique 1 : Le sujet de la session 2 dans le contexte de Bruit comme Problème de Santé Publique

Contexte général : **BRUIT COMME PROBLEME DE SANTÉ PUBLIQUE**

Sujet de la session 2 : Bruit et communication

PROFESSIONNEL

* Sécurité : alertes
  messages linguistiques
  situations d'attention ou d'alerte

* Performance : fatigue
  concentration

Action exigée :
Rendre la connaissance actuelle largement accessible en termes pratiques

NON-PROFESSIONNEL

* Bien-être : perturbation de la communication
  sons applicables "à toute" oreille

Action exigée :
Recherche sur les effets du bruit sur le bien-être auditif

Le graphique identifie deux domaines. D'abord le domaine des problèmes professionnels en situation de travail, dans lesquels les principaux facteurs sont la sécurité et la performance. La sécurité est apparentée à la détection et l'identification des signaux d'alerte ou de messages oraux, et aussi au concept plus vaste d'être conscient de l'environnement acoustique, par exemple entendre les sons des machines et des équipements. En ce qui concerne le second facteur, la performance, je pense à un professeur et à des élèves dans une classe où de hauts niveaux de bruits interfèrent avec la communication, il peut y avoir un problème de tension aussi bien du côté du professeur et que des élèves. On doit aussi penser à d'autres exemples où une bonne communication du discours est indispensable (salles de réunion, bureaux) et où le bruit peut causer de la tension, de la gêne et de l'inconfort. En revoyant les communications présentées, aussi bien dans la session des communications invitées et des communications libres, la plupart font référence à ce domaine de problèmes professionnels. Je pense que nous avons déjà beaucoup de connaissance, fragmentée en plusieurs parties et disciplines. Ce dont nous avons besoin dans ce domaine est le transfert de connaissance : de compléter la connaissance actuelle et la rendre accessible, en termes pratiques, dans le contexte de Santé Publique.

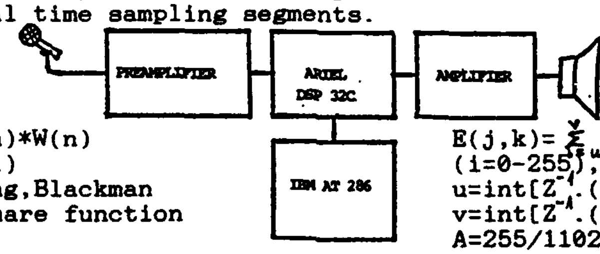
L'autre domaine traite de la situation non-professionnelle, et le principal facteur signalé dans le graphique est le bien-être. La gêne due au bruit en général est un concept très débattu, comprenant beaucoup d'éléments, et à cet égard je veux présenter le concept de bien-être auditif dans la situation d'habitat. Il ne fait pas seulement mention à une communication du discours non troublée, mais à l'audition en général : entendre que quelqu'un rentre par la porte arrière, entendre le bébé pleurer en haut, entendre toutes sortes de sons qui vous laissent conscient de votre environnement acoustique. L'interférence du bruit avec ce type de bien-être auditif se rapporte certainement au domaine de Santé Publique, et je pense que notre connaissance est encore limitée ici. En effet, si quelqu'un veut fixer des limites pour les niveaux de bruit d'intérieur, celles-ci pourraient être basées sur l'interférence avec la communication du discours : un niveau de bruit donné de, disons 60 dB à un mètre devant un parleur, on trouvera pour une situation de salon yypique que la performance en termes de vingt mots commencera à tomber pour des niveaux de bruit dépassant 45 à 50 dB, et ceci définit la limite du bruit. Mais dans un sens plus large de bien-être auditif, cette approche est trop simple. Etre conscient de son environnement acoustique comprend plus que la compréhension du discours non troublé. Ce dont nous avons besoin ici est un inventaire des types de sons qui constituent l'environnement acoustique, et à quels niveaux le bruit commence à perturber la détection et la distinction de ces sons. Celà comprendra aussi souvent des sons faibles, et je pense que vous approcherez 30-35 dB pour le niveau de bruit d'intérieur critique par rapport au bien-être auditif, mais bien sûr ceci devrait être justifié avec des mesures subjectives concrètes.

Ainsi, pour l'avenir et en lançant un message à la session 2, que je quitte maintenant en tant que président, je voudrais dire que dans le domaine du bruit professionnel, l'accent devrait être mis sur le transfert de connaissance : pour rendre le savoir actuel largement accessible dans les différents domaines, en termes pratiques. Pour la situation non-professionnelle, je pense que le concept général de bien-être auditif exige plus de recherche : pour faire le point de tous les bruits pertinents autour de nous en situation de vie typique, et pour étudier l'effet de l'interférence du bruit pour ces sons.

AUTHOR(S) András ILLÉNYI, Klára VICSI, Attila VIG

TITLE : TWO CHANNEL DIGITAL SET-UP TO MEASURE LOUDNESS

For the assesment of noise most regulations, laws, and standardised recommendations are based on A-weighted sound pressure level or related values like L_{eq}, or L_x . These values for quantifying noise has become popular and is being used world-wide. It is known, that these quantities do normaly correspond to what called annoyance [1,2,3,4 5,6].
It has been developed a processing software for preprocessed A/D data, using a DSP-32C Coprocessor Board (made by ARIEL Co.),based on Zwicker loudness criterion, standardised in ISO [7]. In the development of this new device there were always advisable to consider the physical and psychophysical feutures of hearing mechanism [8]. A main topic of these researches is the two channel; biaural technics.In this meaning it was elaborated a two channel digital set-up, computing the phone and sone values by 10ms long real time sampling segments.



$A(n)=A(n)*W(n)$
$(i=0-511)$
W:Hamming,Blackman or square function

$E(j,k)=\sum_{i=u}^{v} B(i)*Y(i,j)$
$(i=0-255)$, $(k=0-105)$
$u=\mathrm{int}[Z^{-1}.(j-6)A$
$v=\mathrm{int}[Z^{-1}.(j+2)A$
$A=255/11025$
$Y(i,j)=b+ax+$
$+(a-25).\sqrt{1+x^2}$

$B(i)=B(i)*S(i)$
S(i) is the weighting factor from Equal Loudness Curves.
$x=D(j).0,1875+0,308-Z(i.1/A)-j$
$a=12,5-6,8014.\exp[-D(j)/3,25]$
$b=27,85-a.1,618-0,1.[D(j)-1]$
The subrutins of DSP card software are as follows: WINDOWING,FFT,EQUAL LOUDNESS LEVEL WEIGHTING,BANDING, FREQUENCZY MASKING IN REAL TIME, MASKING IN TIME.
The frequenczy masking algorithm is made by the Sekey formula [9].
The measuring device is used to investigate the noise annoyance in practical cases comparised the measured loudnes values with conventional noise measures. A new work is the determination of noise imissions from sound sources placed at the ears (Walkman equipments) According the ISO/TC43 Acoustics WG 6, we have investigated the loudness levels of music and speech signals broadcasted by Hungarian Radio. It seems a big difference between the measured A weighted SPL values and loudness values. The loudness level is often more higher as the measured levels by VU meters in broadcasting studios.

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RESEARCH ON NON-AUDITORY PHYSIOLOGICAL EFFECTS OF NOISE SINCE 1988: REVIEW AND PERSPECTIVES

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ABSTRACT

As the range of non-auditory physiological effects of noise is very broad, the studies which deal with these effects automatically show high variability. Traditionally, many studies are laboratory experiments examining acute physiological effects using humans or animals as subjects. The results are in accordance with former studies: Noise stimulates the autonomic nervous system to a higher ergotropic level and therefore has to be considered as a stressor.

Despite the high plausibility of the biological model, the epidemiologic evidence of the harmfulness of chronic noise exposure is weak. The main interest still is focussed on the role of noise as a risk factor for cardiovascular disease. Cross-sectional designs continue to predominate, prospective ones are desirable. All studies are highly susceptible to confounding, effect modification or other problems. The results are contradictory: The hypothesis, that prolonged exposure to high noise levels implies e. g. an increased risk for hypertension or ischemic heart disease neither can be confirmed nor rejected. Findings related to cardiovascular effects other than blood pressure are not consistent.

While no individual study is persuasive regarding the association between industrial noise exposure and elevated blood pressure, research as a whole suggests that such an association exists among persons working for prolonged periods of time under extremely high noise levels without ear protection. Furthermore, preliminary results from Caerphilly indicate, that there is an increased risk for those exposed to traffic noise who are also exposed to high levels of occupational noise.

Another important problem is the potential adverse effect of noise on critical groups. As results from studies of high speed or low-altitude flight indicate, children and the elderly may be vulnerable to blood pressure effects from this noise source. Yet, interpretation of these results is difficult because of low statistical power and inability to adjust for confounders. Mental health seems to be related to noise sensitivity and noise annoyance with the prevalence of psychiatric symptoms being higher among the more annoyed or more noise sensitive people. Effects on pregnancy remain unclear. To date, no chronic effect of noise such as increase of malformations has been observed, whereas the reactivity to noise stimuli seems to be augmented during pregnancy.

The current findings cannot support a consistent relationship between noise exposure and harmful health effects. However, this cannot be construed as evidence of no effect of noise on non-auditory health because of the poor quality of the studies. These circumstances only indicate that further rigorous studies are greatly needed.

RECHERCHES CONCERNANT LES EFFETS PHYSIOLOGIQUES NON-AUDITIFS DûS AU BRUIT DEPUIS 1988: RÉVISION ET PERSPECTIVES

RÉSUMÉ

Comme la gamme des effets physiologiques non-auditifs dûs au bruit est très large, les études sur ces effets montrent une haute diversité. Traditionnellement, beaucoup d'études sont des expériences au laboratoire qui examinent les réponses à court terme en utilisant des hommes ou des animaux comme des sujets expérimentaux. Les résultats sont en accord avec ceux normalement obtenus dans les études précédentes: Le bruit stimule le système nerveux autonome à un niveau ergotropique plus élevé et c'est pourquoi il est à considérer comme un agent stressant.

Malgré la haute plausibilité du modèle biologique, la preuve épidémiologique de l'effet nocif d'une exposition prolongée au bruit est faible. L'intérêt cardinal est toujours concentré au rôle du bruit comme un facteur de risque des maladies cardiovasculaires. Les études transversales continuent

à prédominer, ceux qui sont prospectives sont désirables. Toutes les études sont très sensibles à l'intervention des variables confondantes, à la modification de l'effet etc.. Les résultats sont contradictoires: L'hypothèse qu'une exposition prolongée à des bruits intenses augmente le risque des maladies cardiovasculaires ne peut être ni confirmée ni rejetée.

Tandis qu'aucune étude individuelle est persuasive en ce qui concerne l'association entre le bruit industriel et la pression artérielle élevée, la recherche au total suggère qu'une telle association existe parmi les personnes qui sont exposées pendant beaucoup d'années à des niveaux sonores très élevés sans casque protecteur. En plus, des résultats préliminaires de Caerphilly indiquent qu'il y a un risque élevé pour ceux qui sont exposés au bruit de trafic et en même temps à des bruits très intenses professionnels.

Un autre problème important est l'effet nocif potentiel du bruit sur les groupes critiques. Comme les résultats des études de vol à haute vitesse ou en rase-motte indiquent, les enfants et les vieux peuvent être sensibles aux effets sur la pression artérielle. Cependant, l'interprétation de ces résultats est difficile à cause de la faible pertinence statistique et l'incapacité d'ajuster les variables confondantes. La santé mentale semble être relative à la sensitivité au bruit et la gêne dûe au bruit avec une plus haute prévalence de symptômes psychiatriques parmi les gens plus gênés ou plus sensibles au bruit. Les effets sur la grossesse restent indistincts. Jusqu'à présent, aucun effet de bruit chronique sur le nouveau-né n'a été observé, tandis que la réactivité de la femme enceinte semble être augmentée.

Les résultats courants ne peuvent pas supporter une relation consistante entre une exposition au bruit et des effets nocifs de santé. Néanmoins, cela ne peut pas être pris comme une preuve qu'il n'y ait pas d'effet à cause de la basse qualité des études. Ces circonstances indiquent seulement qu'il faut effectuer d'autres études rigoureuse.

1 INTRODUCTION

The high number of people who complain about noise and who fear detrimental effects to their health seems to be a rather constant phenomenon in industrialized countries. Therefore, public interest in biological effects of noise on man nearly remained unchanged over the past years. In contrast to this, the availability of funds for research on extra-auditory physiological noise effects seems to have decreased in several countries. This may be partly due to a shift to other important environmental problems and partly to the fact that research especially on long-term noise effects has reached a stage where more costly study designs are required. Cohort studies or case-control studies still are the minority; their results indicate that noise may be a risk factor for cardiovascular diseases or hypertension, but the magnitude of these effects is still unclear.

Less costly, but also still important are studies on the pathogenic mechanism of the action of noise on man. The techniques for measuring cardiovascular or biochemical reactions to noise exposure are becoming increasingly sophisticated, which may offer deeper insight in the physiological pathways and possible interactions. Furthermore, as the scale of reactions is widespread, the role of effect-modifiers has to be determined, especially of those which might also help to understand the modification and variability of long-term effects.

2 PHYSIOLOGICAL EFFECTS OF NOISE

Similar to the former years, many studies deal with short-term responses to noise stimuli [4, 5, 6, 16, 29, 30, 33]. Hemodynamic reactions like heart rate, blood pressure, peripheral vasoconstriction and stress hormones represent the traditionally used parameters of noise response, but nowadays the measurements can be taken with more accurate techniques. In addition, with increasing development of technical methods, noise effects also can be studied in physiological subsystems like coronary blood flow [7]. Nearly all of these studies confirm the importance of noise in stimulating sympathetic responses. Therefore, while noise has to be considered a stressor, the role of mainly acoustical, individual or situational variables, which can modify the response pattern, still has to be determined.

With regard to noise characteristics, the probability of provoking strong responses which do not habituate is higher when noise stimuli are not predictable or of high or changing intensity [4, 5, 16]. The importance of sex, age and individual characteristics is less clear. As a tendency it has been

shown, that men show stronger reactions of cardiovascular parameters [37, 40], as do the elderly [18, 31]. Yet the interpretation is very difficult. If this is considered as higher cardiovascular reactivity during short-term exposure, it may imply in the long run that there is a higher risk for cardiovascular diseases. By application of a clustering algorithm Petiot and colleagues [38, 39] made a distinction between sensitive, moderately sensitive and poorly sensitive subjects on the basis of their heart rate. The grouping of their cardiovascular responsiveness was in accordance with the subjects' reactions to noise: Those with low sensitivity showed the smallest reactions and vice versa those who were judged to be very sensitive showed the strongest. Yet, this distinction was not fully consistent with the subjects' qualification as being coronary prone (type A) or coronary non-prone (type B), so that sensitivity in terms of heart rate responses does not automatically indicate an increased risk for cardiovascular disease.

The use of animals in the analysis of reactions to noise is still very frequent [8, 12, 13, 14, 23, 35, 36]. The purpose is two-fold: On the one hand, experiments with animals offer more detailed possibilities under controlled conditions to get a sophisticated insight in the pathogenic mechanisms of noise. On the other hand, audiogenic stress is probably the best controllable and most effective external stressor for studying responses of the autonomous nervous system to exogenic stimuli systematically. In animals, noise nearly always yields the hypothesized results: after relatively short periods of exposure, noise leads to a rise of blood pressure or even hypertension and to an increase of the different stress hormones [8, 12, 13, 14, 23, 35].

Another approach to analyze the physiological effects of noise is the application of pharmacological substances [10, 36]. For example, centrally acting antihypertensive agents like guanfacine cannot block noise-induced vasoconstriction and blood pressure responses which indicates that noise is a potent stressor [10]. Sustained vasoconstriction [10, 33] or elevated ambulatory blood pressure over long periods of time [17] are supposed to cause structural changes in the resistance vessels, which may form the basis for the development of permanent arterial hypertension in humans. If noise cannot be avoided effectively in the future, preventive measures may be of great interest: in an animal experiment it could be shown that the effects of noise on blood pressure were attenuated by exercise training [35]. This finding could be important not only for noise exposure, but also for other environmental stressors.

A particular parameter which deserves further attention are the magnesiums levels in plasma, erythrocytes or other tissues. Results from animal studies demonstrate that noise exposure leads to a decrease of the magnesium level. In addition, if magnesium deficit is given, the effect of noise, e. g. on the rise in blood pressure, is augmented [1, 2]. The pathogenic basis of magnesium deficit seems to lie essentially in the constriction of microvessels. Despite the clarity of these findings, epidemiological studies will have to prove whether disturbances of the magnesium metabolism induced by noise also play a role for humans. So far, in the Caerphilly and Speedwell studies, no association between traffic noise exposure and magnesium levels in erythrocytes could be observed.

3 LONG-TERM CARDIOVASCULAR EFFECTS

3.1 INDUSTRIAL NOISE

Blood pressure, an important predictor of heart disease, continues to be the major effect examined in occupational studies of chronic noise exposure (table 1). Of the 10 studies conducted in noisy industries since 1988, 8 reportedly demonstrated positive associations between noise and blood pressure for at least one subgroup of workers [28, 32, 43, 44, 45, 46, 47, 48], while 2 showed no such relationship [15, 22]. With the exception of one investigator [47] who followed a noise exposed and a control group of workers over a 4-5 year period, all of the studies were cross-sectional in design. It is becoming increasingly evident that these disparate findings may be largely explained by varying levels and duration of exposure to noise, by the presence or absence of mitigating factors such as the use of hearing protectors and other environmental exposures, by failure to control for potential confounding variables, by individual sensitivity to noise as a stressor and by the nature of the study design.

When considered with previous research, these studies suggest that long-term exposure to extremely high noise levels, especially when the ears have been unprotected, may lead to sustained blood pressure elevations [28, 44, 47, 48]. This association is evident when there is long average duration of noise exposure even after adjusting for other major cardiovascular risk factors. A pattern

of higher prevalence of hypertension among subjects with longer exposure to noise compared to workers exposed for a shorter time, has also been observed to occur within both high and low noise exposed groups [46]. However, other industrial exposures which may interact with noise have not been considered. Differences in mean blood pressures between high and low noise exposed groups are relatively small and the prevalence ratios for hypertension are low and variable.

The most rigorous investigation which covered the range of noise from 75 to 104 dBA in a textile mill also demonstrated a dose-response relationship between level of noise and prevalence of hypertension [48]. *In this study, 1101 women had worked in a specific shop with unprotected ears for* their entire working lives. The odds of hypertension increased by 1.2 for each 5 dBA increase in noise (odds ratio - 1.8 at 95 dBA), after adjusting for age, working years, salt intake and family history of hypertension. The data further showed that noise was third in order of importance as a determinant of hypertension after family history and high salt intake.

Table 1: Industrial Noise and Blood Pressure

Study	High Noise dBA	Exposure Duration Years	Hyper-tension Ratios	Variables Controlled
Vermel 1988	85-105	4.2-4.9	3.0	none; many risk factors present
Talijancic 1989	90-102	--	higher	similar anthropometric factors
Tomei 1991	92	20.5	2.7	none; similar on cholesterol, BMI, smoking, family HX, blood glucose
Zhao 1991	104	16.2	1.2 per 5 dB 1.8 at 95 dB	age, family HX, salt intake, working years
Lang 1992	85-100	25+	2.6 (p= .06)	age, BMI, alcohol
Hirai 1991	85-115	10+	no diff.	none
Garcia 1992	high	--	no diff.	none: no stress symptoms, low alcohol use, similar on obesity

Lang and coll. [28] found that blood pressure was not associated with noise exposures of 85-100 dBA after adjusting for age, body mass index and alcohol consumption. However, exposure to noise for 25 years or more was associated with elevated systolic and diastolic blood pressure and with prevalence of hypertension (OR - 2.59, p = .06) after adjusting for the three confounders. For the higher compared to the lower noise exposed group, the means for systolic and diastolic blood pressure were higher by 10.3 mm Hg and 8.3 mm Hg, respectively. Although no information was given as to the use of hearing protectors, it is doubtful they had been used throughout the 25 year period of employment.

The several cross-sectional studies which showed no harmful effects on blood pressure failed to account for confounding variables and to describe duration and characteristics of exposures [15, 22]. Hirai and coll. [22] found hearing loss higher in laborers exposed to stressful noise than in controls, but no differences in systolic or diastolic blood pressures between the noise exposed and unexposed and no association of blood pressure with hearing loss. Furthermore, a comparison at baseline and after 10 years for 868 workers showed similar increments in blood pressure and in hypertension for the noise exposed and lesser exposed workers. Temperature in the workplace was the only factor controlled in the analysis [22].

Although occupational settings remain the major source of exposure to high levels of continous noise, the paucity of studies and the poor methodologic quality of existing research make it difficult

to draw conclusions. On the basis of current and past research, it seems unlikely that studies in industries where adequate noise protection is maintained will show very strong effects of noise on the cardiovascular system. Prospective studies in work environments with currently permissible noise levels and sustained use of hearing protectors are needed to clarify the conditions under which noise exposure may adversely affect the cardiovascular system.

3.2 ENVIRONMENTAL NOISE

Environmental noise has received increasing attention as a potential stressor on the cardiovascular system as larger percentages of the population become exposed to road and air traffic noise during both day and night hours (table 2). Preliminary results from the ongoing Caerphilly and Speedwell prospective studies provide no convincing evidence of an association between exposure of men to traffic noise and ischemic heart disease or levels of known risk factors for ischemic heart disease including high blood pressure [11]. Noise levels were found to be relatively low with only 5-10 % of the men exposed at levels likely to be of clinical importance. Subjects were grouped in 5 dB categories of traffic noise level, ranging from 51 to 70 dBA. When the data were pooled and the lower noise exposed group (noise ≤ 60 dBA) compared to the highest exposure group (noise 66-70 dBA), the relative risk for ischemic heart disease was only 1.1 and not statistically significant [3]. The pooled sample sizes from Caerphilly and Speedwell were apparently too small to allow detection of weak associations and adequate adjustment for the multiple confounders.

Table 2: Road Traffic Noise and Cardiovascular Effects

Study	Design	Noise Level dBA	Findings
Caerphilly & Speedwell	prospective	51-70	Ischemic Heart Disease RR = 1.1
Berlin	population-based case-control (incident cases)	≤ 60-80	Myocardial Infarction OR = 1.2
Luebeck	cross-sectional	high vs low	Hypertension OR = 1.3

These findings are consistent with those from population based case-control studies in Berlin [3] and from the cross-sectional Luebeck traffic noise study [21]. The Berlin studies, based solely on incident cases in the defined populations, reported somewhat higher noise levels ranging from ≤ 60 dBA to 80 dBA. A relative risk for myocardial infarction of 1.2 was observed after adjustment for multiple confounders. The Luebeck study of 2315 citizens indicated a slightly higher prevalence of hypertension for men living in the high exposure areas compared to the low noise areas (odds ratio - 1.32) after controlling for age, body mass index, alcohol use, education, duration of residence and employment status [21]. Babisch [3] has concluded that 70 dBA may be the threshold for traffic noise effects that are detectable by epidemiological methods and calls for more studies to further elucidate this relationship.

Recent studies of military low-altitude flight noise with its unusually high maximal levels and rapid rise in sound level have shown no increase in cardiovascular disease. One study of a small group of children showed higher systolic blood pressures (group difference 9 mm Hg) in 9-13 year old girls, but not in boys, in the area where exposure was highest. Significantly lower heart rates were observed for boys in the low-altitude flight area as compared to controls. These findings could not be verified in similar field investigations [26].

Ising [24] has suggested that even the small risks observed for road traffic noise may be important since such a high proportion of the population is exposed. Physiological effects from cumulative

noise dose from multiple sources and the interactive effect of noise with other stressors need attention. In the community, the cardiovascular effects resulting from noise annoyance and noise disturbed sleep warrant investigation.

4 EFFECTS OF NOISE ON CRITICAL GROUPS

4.1 EFFECTS ON PREGNANCY

The hypothesis that noise could exert harmful effects on pregnancy is mainly based on the model that noise-induced vasoconstriction leads to a decrease of the uteroplacental blood supply and that elevated levels of stress-hormones due to noise may cause higher contractility of the uterus. Of course, the possibilities of proving these special effects with humans are limited. This may be the reason why shortlasting experiments (15 min exposure to 90 dB white noise) with pregnant women could not confirm these mechanisms [20]. Therefore, these negative findings do not exclude potential longterm effects, especially because the general physiological mechanism of how noise acts on man has been established by numerous other experiments.

The range of possible outcomes refers to spontaneous abortion, prematurity, low birth weight and malformations. Practically all recent studies which deal with these effects are confined to occupational noise exposure. This implies that noise load may be fairly high, which increases the probability of detecting small risks. Yet, as a matter of fact, occupational noise is never an isolated exposure condition, but is combined with other simultaneously occurring exposure conditions. Even if these influences are controlled for statistically, no clear relationship between noise and pregnancy outcomes like prematurity, low birth weight or selected structural malformations could be established [9, 19, 27, 34].

In contrast to these findings, positive effects were observed with respect to elevated maternal blood pressure levels during pregnancy. Two studies indicate that noise exposed pregnant women may have a higher risk of hypertension, especially in combination with shift work or lifting of heavy loads [42, 34].

4.2 EFFECTS ON NOISE SENSITIVE SUBJECTS

The question of whether noise impairs mental health has already been discussed for many years. One key factor might be noise sensitivity [42]. It could be shown that noise sensitivity is clearly related to noise annoyance and also to psychological disorders showing higher rates of annoyed and psychologically impaired subjects among the most noise sensitive group. Therefore, noise sensitivity is suspected to be either an indicator of an increased vulnerability, not only for noise, but also for other stressors, or an indicator of a tendency to overreport and to complain. Anyway, the potential role of noise exposure in the genesis of psychological morbidity seems to be not very powerful, as a significant relationship could be found only in the strata of the less sensitive group.

5 CONCLUSIONS

The results of the studies on acute physiological effects continue to confirm the role of noise as a potent stressor which, at least in animals, leads to structural changes in vessels. Yet, the short-term responses of humans show high variability, so that a bundle of effect-modifiers, which individually change noise effects, has to be assumed. Some of these effect modifiers have been identified, like noise sensitivity, coping strategies or noise annoyance. Their impact on the genesis of physiological effects is still unclear.

Despite the biological plausibility of noise as a risk factor for cardiovascular disease, studies on long-term effects to date show equivocal results. Increased risk for hypertension is evident primarily when workers are exposed for 20-25 years to industrial noise above currently permissible levels and do not consistently use hearing protection. A major problem is that cardiovascular diseases are nonspecific for noise exposure and large sample sizes are required to permit adjustment for potential confounders. A particular need in occupational settings is to study the effects of sound attenuation on physiological outcomes.

As yet, no methodologically sound study of adequate sample size has demonstrated a statistically significant increase in cardiovascular disease due to road traffic noise. The possibility that road traffic and other general environmental noise may adversely affect the cardiovascular system indirectly through annoyance and noise disturbed sleep needs to be explored in future research.

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ROAD TRAFFIC NOISE AND HEART DISEASE RISK: RESULTS OF THE EPIDEMIOLOGICAL STUDIES IN CAERPHILLY, SPEEDWELL AND BERLIN

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Abstract

The hypothesis that prolonged exposure to road traffic noise causes ischaemic heart disease (IHD) was tested in cross-sectional, case-control, and cohort studies in middle-aged men. In the Caerphilly and Speedwell studies, 2512 and 2348 men, respectively, aged 45-59 years were seen in the initial cross-sectional phase and at intermediate follow-up intervals of approx. 4 and 10 years. The prevalence ratio (95% confidence interval) of IHD at the beginning of the studies was 1.2 (0.7-2.0) and 1.2 (0.8-1.9) for men in the highest noise category of the daytime outdoor traffic noise level (66-70 dB(A)) as compared to those in the lowest noise category (51-55 dB(A)) after adjustment for possible confounding. The risk factor profile of these men was slightly shifted towards a higher IHD risk. It was calculated that a relative risk of IHD incidence of 1.1 was to be expected for those men. In the first follow-up investigations, adjusted relative risks of 0.5 (0.2-1.7) and 0.7 (0.3-1.8) were observed. These, however, were based on very few cases in the highest noise group. In the final follow-up investigations after ten years, which were available for the Speedwell cohort yet, an adjusted relative risk of 1.2 (0.8-1.9) was found. In the Berlin case-control studies, comprising a prestudy and a main study, 121 and 693 male patients (survivers), respectively, with acute myocardial infarction (MI) and 152 and 3865 controls, respectively, were seen. The subjects were aged 41-70 years. The odds ratio of IHD incidence was 1.3 (0.5-3.8) and 1.2 (0.8-1.7), respectively, for men in the highest noise category (71-80 dB(A)) as compared to the lowest noise category (51-60 dB(A)) after adjustment. In a subsample of men who had not moved within the past 15 years, the odds ratio was 1.3 (0.9-2.0) which was borderline significant ($p<0.10$). Also, cross-sectional analyses of self-reported MI among the random sample of controls revealed a relative prevalence of 1.2 (0.7-2.0) for men who had not moved within the past 15 years in the highest noise category. Some methodological issues and the relevance of low relative risks will be discussed.

Introduction

In extra-auditory noise research the question whether prolonged exposure to noise causes any health effects is not fully answered yet, in particular with respect to noise in the home environment. Given the conflict of competing risks and limited resources, decision making in public health will have to rely on risk estimations to spend its resources most efficiently.

In general, toxicology and epidemiology are the scientific tools to provide the information needed. The effects of low exposures at ambient levels can often be extrapolated from effects of higher exposures in the occupational environment. This can be done when specific toxic mechanisms are known. For example, for ionizing radiation, asbestos or benzene teratogenic or carcinogenic effects are identified. However, for noise no such mechanisms are known except ear damage. To study the non-auditory health effects of low level environmental noise, epidemiological research is needed. This is due to the fact that noise acts as a non-specific physiological stressor on the human organism. This either directly, or indirectly via emotional stress reactions. In the case of environmental noise levels, the first may apply to sleep while the latter applies to disturbances and annoyance reactions. The scientific basis for epidemiological noise research is the following:

1) Laboratory experiments have shown that acute noise exposure at occupational noise levels affects the sympathetic and endocrine system resulting in temporary humoral, cardiovascular and metabolic changes.
2) Epidemiological research on cardiovascular diseases has shown that many of the reaction parameters detected in noise experiments are risk factors.
3) Combined stress experiments have shown that physiological reactions occur at ambient noise levels when noise interferes with activities.
4) From social surveys it is known that traffic noise causes strong disturbance and annoyance reactions in the population.
5) From general stress research it is known that adaption is a compensating physiological response to chronic stress that may be exhausting in the long run and may lead to adjustments in the setpoints for fine control processes in the organism.

On this basis, the well founded hypothesis developed that long-term exposure to noise affects the cardiovascular system and in particular causes ischaemic heart disease (IHD). This hypothesis was tested with respect to road traffic noise. The simple epidemiologic approach is to test whether subjects who live on noisy streets develop the disease more often than less exposed subjects. Certainly, it would have to control for possible confounding factors. The studies refered to are the Caerphilly and Speedwell Heart Disease Studies and the Berlin Traffic Noise Studies. The first were carried out in the United Kingdom in the small town of Caerphilly and in a district of the major British town Bristol. The latter were carried out in the German city of Berlin. The research was funded by the Commission of the European Community, the German Federal Environmental Agency and the Berlin Senate.

CAERPHILLY AND SPEEDWELL STUDIES

Methods

In two representative samples of 2512 (Caerphilly) and 2348 (Speedwell) men respectively, the relationships between road traffic noise level outdoors and cardiovascular risk factors, prevalence of IHD, and incidence of IHD was investigated in middle-aged men. These cohort studies include cross-sectional and longitudinal design components. Both studies follow the same protocol which allows the pooling of data. Caerphilly men were chosen from the electoral roll and General Practitioner records, Speedwell men from the age-sex registers of 16 General Practitioners working out of two Health Centres. Response rates about 90% were obtained. By the time the men were first seen at the clinics in 1979-83 and 1979-82, they were aged 45-59 (Caerphilly) and 45-63 (Speedwell) years respectively. Intermediate follow-up examinations were conducted after 3 and 5 years, respectively, and the final 10-years follow-up examinations have just recently been finished in Speedwell while the corresponding Caerphilly data will be available later this year.

The daytime average sound pressure level ($L_{eq,6\text{-}22\ hr}$) as derived from traffic noise measurements taken all over the study areas, was used as an indicator of traffic noise exposure. It was categorized in 5 dB(A) groups ranging from 51-70 dB(A). A constant shift between the daytime and night time noise levels of 7-8 dB(A) was found regardless of 24 hour street traffic volume. The prevalence of ischemic heart disease was assessed using the London School of Hygiene chest pain questionnaire (angina pectoris, myocardial infarction) and the ECG recordings (ECG ischaemia). The incidence of major IHD was coded if one of the following criteria was fulfilled: Death due to IHD (ICD 410-414), clinical myocardial infarction (notified admission to hospital due to acute myocardial infarction coded ICD 410) or ECG myocardial infarction (major ECG changes by Minnesota coding). To account for possible confounding, the control variables Age, Social class, Marital status, Employment status, Physical activity at leisure and at work, Smoking, Body mass index, Family history of myocardial infarction and Disease status regarding several common chronic diseases were assessed. The statistical analyses comprised stratified crosstabulation, multiple regression and multiple logistic regression technics. Full details are given elsewhere [1,2,3].

Results

The number of IHD cases after the initial 1st. phase and the follow-ups are given in *Table 1*: In Caerphilly 438 prevalent IHD cases at the beginning and 153 incident IHD cases after 5 years were identified; the 10-years follow-up data are not available yet. In Speedwell 340 prevalent IHD cases, 98 incident IHD cases after 3 years and 290 IHD incident cases after 10 years were identified. The 10-years follow-up data came in shortly before this congress, therefore it must be pointed out that all these results are preliminary. The IHD incidence rate in the study samples was about 1.2% per year. After the first follow-up 88% in Caerphilly and 82% in Speedwell did not move at all, while 98% in Caerphilly and 93% in Speedwell experienced no change in traffic noise exposure. After the final follow-up 74% in Speedwell did not move, while 81% of those who did not move out of the study area experienced no change in traffic noise level.

Table 2 gives (model-) adjusted ratios of IHD prevalence from the 1st. phase of examination separately for each cohort. Given are relative odds and 95%-confidence intervals for the men in each noise category, the quietest category of 51-55 dB(A) serving as a reference. A tendency towards an increase in the relative risk with traffic noise levels above 60 dB(A) can be seen. The point estimate of the relative risk in the highest noise category of 66-70 dB(A) was 1.2. However, none of the results was statistically significant.

Figure 1 condenses our finding on the prevalence of risk factors in relation to traffic noise, which were presented at the last congress in Stockholm [4]. The relative risk factor profile gives the relative prevalence of high/low values (upper/lower quintile of the distributions) in 9 biological risk factors, for the men of the highest noise category compared to those in the lowest. The graph refers to the pooled subsamples of men with no history for several chronic diseases. The bars indicate the 95%-confidence intervals of the prevalence odds ratios. Blood lipids and haemostatic factors were slightly shifted towards relative risks above one but not blood pressure. At lower noise levels no associations with risk factors were found that were consistent with a dose-response criterion. On the basis of these risk factors, an expected relative risk for IHD incidence of 1.1 for the men in the highest noise group of each cohort was calculated by a logistic model using the first follow-up data.

By contrast, in the first follow up (model-) adjusted relative risks of 0.5 and 0.7 respectively were observed for these men. *Table 2* gives the cumulated incidence odds ratios across noise categories. However, the confidence intervals are wide, which is due to the very few cases, less than 10, in the 66-70 dB(A) group, which reflects the much smaller amount of subjects exposed to higher traffic noise levels in the random population sample. *Table 2* also gives the corresponding results after 10 years of follow-up for Speedwell. Here a point estimate of the relative risk of 1.2 was found for men in the highest noise category. This only in the subsample of men with no history of several chronic diseases. The finding is more stable than after 3 years of follow-up (24 cases in the highest noise group) and, although not significant, consistent with the calculated expected relative risk of 1.1.

BERLIN STUDIES

Methods

The road traffic noise studies carried out in Berlin are case-control studies that comprise a pre- and a main study. Study subjects were middle aged men, between 31 and 70.

The pre-study was hospital based. For one year all incident cases were collected who have been treated for acute myocardial infarction (AMI) in a major hospital of the city, and who survived this event. These were 109 subjects, who fullfilled the inclusion criteria, which were age, male sex, German nationality, residence in Berlin for at least 15 years and diagnostic criteria (acute MI/ ischaemia, transmural cardiac infarction with localization data, partial layer infarction /ischae-mia, ECG ischaemia, recurrent acute cardiac infarction, pre-infarction syndrome, serochemical infarction and therapeutic criteria (thrombolytic therapy, aortocoronary bypass, percutaneous transluminal coronarangioplasty correlating closely in time with the occurance of infarction). From the ENT

department of the same clinic 134 controls with same age/gender characteristics were chosen by frequency matching. Because all subjects were patients, the response rates were high, around 90%. The subjects were asked to fill in a questionnaire to supply information about present and former addresses, residence time and orientation of rooms in relation to the street in the address. This pre-study gave an estimate about what relative risk could be expect in the main study.

A more powerful study was designed by extending the study design to all major clinics all over former West Berlin. Because of the relatively isolated island situation a clearly defined catchment area was given. Again for one year, all survivers with incidence of AMI were collected from 17 major hospitals with emergency board out of 24 identified as having intensive care units in former West Berlin. These were 645 German subjects who participated and fullfilled the inclusion criteria, making a participation rate of 90%. From enquiries to other clinics not involved in the study, it was estimated that 80-85 % of all non-fatal acute cases in the source population were identified that have gone through hospital intensive care units. Since the 20-25 % of cases lost mostly refer to inner city hospitals (more noisy streets), this may act conservatively on the results. Unlike the pre-study, this main study was population-based. This means that the controls were a random sample of the source population with same age/gender characteristics as the cases drawn from the local registration office. Of the men identified, we were able to interview 3390 who full-filled the inclusion criteria, a participation rate of 64%.

Traffic noise in both studies was determined by noise maps of the daytime (6-22 h) equivalent continuous A-weighted sound pressure level outdoors, provided by the city authorities and based on traffic counts. The men were grouped into 5 dB(A) categories ranging from ≤60-80 dB(A), which means that higher categories of traffic noise exposure were considered than in the Caerphilly and Speedwell studies. To take account of moves, the retrospective noise exposure of different homes was averaged (weighted by residence time) to obtain a kind of 15 years lifetime dose related figure, but subsamples were also considered that had not changed their address over that period (about 60%). To account for possible confounding, the control variables Age, Social class, Employment status, Smoking, Body mass index, Family status, Shift work and Area (in terms of inner or suburban city districts) were assessed. Full details are given elsewhere [5].

Results

The number of men in each noise category are given in *Table 1*. *Table 3* gives the relative risk of AMI from the pre-study in each noise category, with the quietest (≤60 dB(A)) serving as a reference. With the exception of the 61-65 dB(A) category, we find an increase in the adjusted odds ratio with noise level of 1.3 and 1.8 in the highest categories of 71-75 dB(A) and 76-80 dB(A). Due to the small sample size, the confidence intervals are wide. When these categories are combined, the point estimate for the relative risk for men living on streets with daytime outdoor noise levels above 70 dB(A) is 1.3, still insignificant.

Table 3 also gives the results for the main study. The effects are smaller than in the pre-study. In fact, there is not much indication of an increased risk for the subjects in the noise categories below 71 dB(A), reflecting a dose-response relationship. However, there is a trend of increasing relative risk for AMI of 1.1 and 1.5 in the higher noise categories of 71-75 and 76-80 dB(A), but this is not significant as you can see from the 95%-confidence intervals that include the relative risk of one. *Table 3* also gives the results in the subsample of men who have not moved in the past 15 years. The relative risks here are a little larger, 1.2 and 1.7 in the highest noise categories. When these highest noise categories are combined, the point estimate for the adjusted relative risk is 1.3 which is borderline significant ($p < 0.10$). Since the random sample of controls in the main study provided an independent data base, additional cross-sectional analyses were performed on the relationship between road traffic noise level and self-reported history of diagnosed myocardial infarction as answered in the questionnaire. These analyses were restricted to the subgroup of men who did not move over a period of 15 years retrospectively. The results are given in *Table 3*. Again, relative risks above 1 are observed in the noise categories above 70 dB(A) outdoor traffic noise level, with a magnitude of 1.2 if the highest categories are combined, which is very consistent with the other finding, but also not significant.

Conclusions

The results of our studies, although not significant, give some indications that living on noisy streets with daytime traffic noise levels outdoors of more than 65 to 70 dB(A) may be associated with a slightly increased risk for ischaemic heart disease of about 1.1 to 1.3 which needs further proof.

In environmental epidemiology one is usually dealing with small magnitudes of the effect measure. However, since the number of exposed people in the general population is often high, even small relative risks may be relevant to public health. For example, if one assumes a 20% increase in IHD risk in subjects exposed to noise levels of more than 65 dB(A) and takes into account that about 10% of the population are exposed, approx. 2 in 100 IHD cases would have to be considered due to the noise. Certainly, the studies presented here have not proven the hypothesized relationship between traffic noise and ischaemic heart disease risk. But, if decision makers feel that such a relative risk might be important, more analytic noise studies are needed.

What recommendations can be given? Statistical proof of small effects has to be founded on large samples. From power calculations it can be deduce that sample sizes of more than 10,000 would be required. On the other hand, even non-significant studies may contribute to the picture. Meta analyses can be a method to increase precision and estimate the magnitude of the effect by combining results from several studies [6]. However, we lack enough suitable studies. But still, the detection of relative risks below approx. 1.2 by means of observational epidemiological methods is hard to achieve even with very specific methods of measurements due to random variation, residual confounding or insufficient control of similarly weak confounders [7,8]. Experimental epidemiologic methods (intervention studies) may be appropriate tools to detect small noise effects, if feasible.

Further traffic noise studies should comprise areas and subjects exposed to levels higher than $L_{eq,day}$ = 70 dB(A) for larger magnitude of effect. They should focus on *sensitive subgroups*, if such groups can be predetermined [9]. Precise assessment of disease and exposure (including room orientation and time activity patterns) reduces misclassification, which can be a source of bias or random error in the data. The composition of a cross-sectional or cohort study should include equal numbers of high and low exposed subjects. Looking at continuous variables such as risk factors rather than at (rare) discrete events reduces the required sample size considerably. However, such research should be accompanied by assessments of disease risk to make the results manageable in health policy. Consistency, dose-response relationship and biological plausibility are important issues in the interpretation of findings [8].

In accordance with the stress model, variables of disturbance and annoyance may be better predictors for cardiovascular effects than the noise level. *Figure 2* which refers to the Speedwell study supports this idea. In addition to the association between traffic noise level and IHD incidence, questionnaire item sum scores of annoyance and disturbances due to traffic noise are incorporated in the graph. In the highest category we find a steep increase in relative risk in these subjective determinants of exposure. Our future analyses of the Caerphilly and Speedwell studies will continue to focus on this. However, from the decision making point of view we have to bear in mind that annoyance cannot be regulated, but noise level can. Therefore every noise research should in some way relate to the noise level.

Figure 3 is a first step of a meta analytic approach. It collates results from different studies on the association between traffic noise and ischaemic heart diseases [10,11,12]. Given are relative risks for IHD between extreme groups of noise exposure. With the exception of the intermediate follow-up findings from the Caerphilly and Speedwell study, a slight shift of the point estimate towards relative risks above one can be seen. The Caerphilly and Speedwell studies and the Berlin studies, could be pieces in the puzzle of quantifying the IHD-risk for subjects exposed to traffic noise.

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Tables and Figures

Table 1: Sample sizes

Number of men	Traffic noise level outdoors 6-22 hr [dB(A)]						
	51-55	56-60	61-65	66-70	71-75	76-80	Total
Caerphilly							
Total sample	1850	211	318	133	—	—	2512
Prevalent IHD	324	35	54	25	—	—	438
Incident IHD (5 years)	107	17	22	7	—	—	153
Speedwell							
Total sample	1633	262	214	239	—	—	2348
Prevalent IHD	228	34	37	41	—	—	98
Incident IHD (10 years)	211	23	24	32	—	—	290
Berlin - Pre							
Cases	78		10	12	8	1	109
Controls	103		10	12	8	1	134
Berlin - Main							
Cases	528		43	32	29	13	645
Controls	2827		193	185	141	44	3390

Table 2: Caerphilly and Speedwell studies, relative risk of ischaemic heart disease (IHD)

Relative risk (95% confidence interval)	Traffic noise level outdoors 6-22 hr [dB(A)]			
	51-55	56-60	61-65	66-70
Caerphilly				
Total sample	(N = 2512)			
Prevalent IHD	1.0	1.0 (0.7-1.3)	1.0 (0.8-1.3)	1.1 (0.7-1.6)
Incident IHD (5 years)	1.0	1.4 (0.9-2.3)	1.2 (0.8-1.9)	0.9 (0.4-2.0)
Sample of men with complete data for				
risk factors and covariates	(N = 2158)			
Prevalent IHD*	1.0	1.0 (0.6-1.5)	1.1 (0.8-1.6)	1.2 (0.7-2.0)
Incident IHD (5 years)*	1.0	1.2 (0.7-2.3)	1.3 (0.8-2.2)	0.5 (0.2-1.7)
Speedwell				
Total sample	(N = 2348)			
Prevalent IHD	1.0	0.9 (0.7-1.3)	1.2 (0.9-1.7)	1.2 (0.9-1.7)
Incident IHD (3 years)	1.0	0.7 (0.3-1.4)	1.1 (0.6-2.0)	0.8 (0.4-1.6)
Incident IHD (10 years)	1.0	0.7 (0.5-1.0)	0.9 (0.6-1.3)	1.0 (0.7-1.5)
Sample of men with complete data for				
risk factors and covariates	(N = 2118)			
Prevalent IHD*	1.0	1.0 (0.6-1.5)	1.2 (0.8-1.9)	1.3 (0.8-1.9)
Incident IHD (3 years)*	1.0	0.6 (0.3-1.5)	1.3 (0.6-2.5)	0.7 (0.3-1.8)
Incident IHD (10 years)*	1.0	0.7 (0.2-1.1)	0.9 (0.4-1.4)	1.0 (0.6-1.5)
Subsample of men with no chronic diseases				
and complete data for covariates	(N = 1907)			
Incident IHD (10 years)*	1.0	0.8 (0.5-1.3)	0.7 (0.4-1.3)	1.2 (0.8-1.9)

* Adjusted for covariates by logistic regression model

Table 3: Berlin studies, relative risk of myocardial infarction (MI)

Relative risk (95% confidence interval)	Traffic noise level outdoors 6-22 hr [dB(A)]				
	≤ 60	61-65	66-70	71-75	76-80
Berlin - Pre					
Total sample	(N = 243)				
Incident MI	1.0	1.3 (0.5-3.4)	1.3 (0.5-3.1)	1.3 (0.5-3.5)	
Incident MI*	1.0	1.5 (0.6-3.9)	1.2 (0.5-2.9)	1.3 (0.5-3.8)	
Subsample of men who did					
not move in past 15 years	(N = 155)				
Incident MI*	1.0	1.3 (0.5-3.3)		1.2 (0.3-4.1)	
Berlin - Main					
Total sample	(N = 4035)				
Incident MI	1.0	1.2 (0.9-1.7)	0.9 (0.6-1.4)	1.1 (0.7-1.7)	1.6 (0.9-3.0)
Incident MI*	1.0	1.2 (0.8-1.7)	0.9 (0.6-1.4)	1.1 (0.7-1.7)	1.5 (0.8-2.8)
Subsample of men who did					
not move in past 15 years	(N = 2582)				
Incident MI*	1.0	1.0 (0.7-1.5)		1.3 (0.9-2.0)	
Subsample of controls who did					
not move in past 15 years	(N = 2193)				
Prevalent MI*	1.0	0.8 (0.3-1.7)	0.9 (0.5-1.6)	1.1 (0.6-2.1)	1.4 (0.5-3.7)
Prevalent MI*	1.0	0.8 (0.5-1.4)		1.2 (0.7-2.0)	

* Adjusted for covariates by logistic regression model

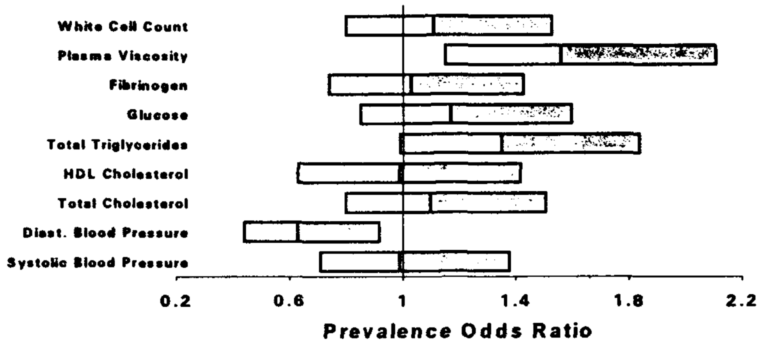

Figure 1: Relative risk factor profile (66-70 dB(A) group vs. 51-55 dB(A) group)

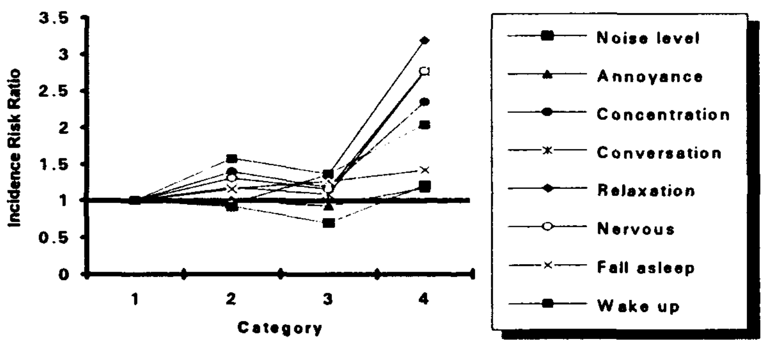

Figure 2: Relative risk of IHD incidence (Speedwell study) in relation to traffic noise (noise level categories), annoyance and disturbances (categories as answered on a questionnaire)

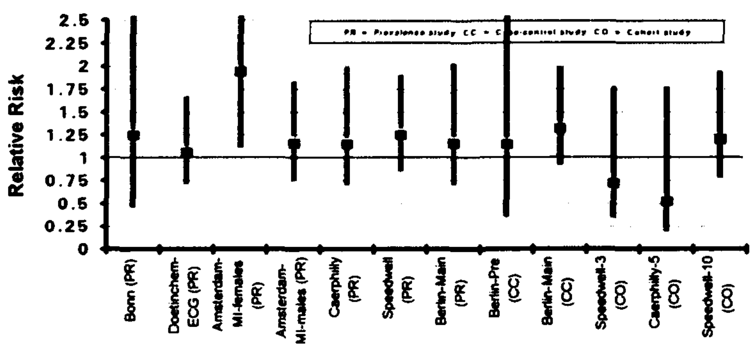

Figure 3: Relative risk of ischaemic heart diseases (extreme group comparisons) from different road and air traffic noise studies

ROAD TRAFFIC NOISE, NOISE SENSITIVITY AND PSYCHIATRIC DISORDER: PRELIMINARY PROSPECTIVE FINDINGS FROM THE CAERPHILLY STUDY

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Abstract:

Aircraft and traffic noise exposure may cause acute psychological symptoms and increased tranquilliser use but probably do not cause increased rates of psychiatric disorder in the community. It is hypothesized that noise sensitivity may be a vulnerability factor for psychiatric disorder caused by noise. Preliminary prospective results are presented from the Caerphilly Study, South Wales, UK in 1255 men. Noise sensitivity predicts psychiatric disorder at follow up in this sample but noise is not related to psychiatric disorder. It seems that noise sensitivity is an indicator of a low level of psychological morbidity but does not interact with noise level to influence psychological health.

Introduction:

Environmental noise causes distress in the form of annoyance, (1). In view of generally increasing levels of ambient noise, an important public health question is whether environmental noise goes beyond this to cause psychiatric disorder. To examine this noise exposure gradients, concerning largely aircraft and traffic noise, have been related to psychiatric disorder measured as psychological symptoms, psychotropic drug use, mental hospital admissions, and measurement of psychiatric disorder in the community by questionnaire.

Reports of 'headaches', 'restless nights' and 'being tense and edgy, have been related to high levels of aircraft noise (2, 3) as has irritability (4). An explicit link between symptoms and noise in the questions in these cross-sectional surveys may have led to response bias (5). Grandjean's study (6) around three Swiss airports which made no explicit links between aircraft noise and health found no association between noise and symptoms. In the West London Survey (7) 'depression', 'irritability', 'waking at night' and 'difficulty getting to sleep' were more common as acute symptoms (within last 2 weeks) in high aircraft noise areas, but as chronic symptoms in low noise areas. This apparent contradiction may be explained by poorer pre-existing ill health in the low noise areas leading to more chronic symptoms. It highlights a major problem for these studies: unless there is accurate matching for social disadvantage between high and low noise areas, social disadvantage may confound the association between noise level and psychiatric disorder.

Health service use by noise exposure shows similarly mixed results; general practitioner contact rate and overall drug use has been associated with noise level in some studies (6,8) but not in others (9). However, an increase in sedative and sleeping pill use has been associated with an increase in levels of aircraft noise which was not found in a control area where noise remained unchanged (8).

Early studies found associations between admissions to psychiatric hospitals and aircraft noise exposure (10; 11; 12). There have been methodological criticisms of these studies related to definition of noise areas, population denominators and adjustment for confounding factors (13, 14).

Further comprehensive studies (15, 16) have found, at most, a moderating rather than a causal role for noise on psychiatric hospital admission. However, Kryter (17) in a reanalysis of this latter data did find an association between aircraft noise and psychiatric admission rates taking into account further sociodemographic indices.

As noise, at best, may only have a minor influence on hospital admission rates, a more appropriate form of study for determining whether noise causes psychiatric disorder is the community survey using standardised measurement of psychiatric disorder. In both the pilot study (18) and the West London Survey (19) no overall association was found between aircraft noise exposure measured by the Noise and Number Index and psychiatric disorder measured by the General Health Questionnaire (20) except in two subgroups: 'finished full time education at >19 years' and 'professionals'.

It may be that certain sectors of the population are more vulnerable to the psychological effects of noise. A candidate vulnerability factor is noise sensitivity, a measure of attitudes to noise in general, which is both a risk factor for noise annoyance and is also consistently associated with psychiatric disorder and neuroticism (18, 21, 22, 23, 24). In one survey, noise sensitivity as one of asthenic sub-clinical symptoms, has been found to predict further depression (25).

To pursue this question further, the association between traffic noise exposure, noise sensitivity and psychiatric disorder was examined in the cross sectional results of the Caerphilly Study in South Wales, UK. This study has the advantage over the West London Survey of not being selected for noise zone. The West London study may have been biassed by prolonged noise exposure. For example, it may represent a population of 'survivors' in noise, the most vulnerable to noise having moved away or having never moved into the noisy area.

There was no association between noise exposure and psychiatric disorder in the cross-sectional analysis of the Caerphilly Study except, paradoxically, among those of intermediate and low noise sensitivity where rates of psychiatric disorder increased with increasing noise levels. In the highest noise sensitivity tertile there were high levels of psychiatric disorder regardless of noise (26). This paper reports the preliminary associations between noise measured at baseline, and noise sensitivity, as a moderating factor, on psychiatric disorder measured prospectively.

Method:

The Caerphilly Collaborative Heart Disease Study is a prospective study of risk factors for ischaemic heart disease in men. All men between 50-64 years living in Caerphilly, South Wales, UK and its environs were invited to attend a screening clinic where physiological measurements were made and questionnaires completed (27).

Traffic Noise Exposure. Traffic noise maps of the study area were derived from street measurement of A-weighted sound pressure level (28). The respondents' homes were randomly distributed due to the sampling procedure. In accordance with the noise measurements, the subjects were grouped into 5 dB categories of traffic noise emission level, in terms of 'Leq' referring to the period from 6 o'clock in the morning to 10 o'clock at night and a distance of 10 metres from the street. Daytime outdoor noise level was used as a general descriptor of traffic noise load in the street. Due to the architecture of the housing, traffic noise emissions and emission level (perceived at the facades), were very similar for the vast majority of the men.

Noise sensitivity was measured by Weinstein 10-item self-report noise sensitivity scale (29) for which Cronbach's alpha was 0.78 in a subsample.

Psychi[illegible] disorder was measured by Goldberg's 30-item General Health Questionnaire (30). This is [illegible] screening questionnaire for depression and anxiety, the type of morbidity expected in a comm[illegible] sample. It was validated against psychiatric interview in a subsample and a case threshold of 4/5 was established (10). Trait anxiety was measured by the Trait scale of the State-Trait Anxiety Inventory (11).

Results:

2398 men were present in the baseline sample which was the first follow up of the survey. The response rate to the survey was 89% Preliminary prospective GHQ data is now available on 1255 men. There was no association between noise level at baseline and psychiatric disorder measured prospectively (Table 1).

Table 1: Mean GHQ scores (standard error) measured prospectively by noise level at baseline

	Noise Level - dB (A)				
	51-55	56-60	61-65	[illegible]	[illegible]
Mean GHQ Score	3.12(0.17)	3.99(0.47)	3.28(0.34)	[illegible]	[illegible]
% of GHQ high scorers	23.9	34.2	[illegible]	[illegible]	[illegible]
n	850	114	206	85	
Total - 1255					

There was, however, an association between Weinstein noise sensitivity [illegible] baseline and psychiatric disorder measured prospectively (Table 2).

Table 2: Mean GHQ scores (standard error) measured prospectively by Weinstein Noise Sensitivity at baseline

Noise Sensitivity	Adjustment for Noise level	Adjustment for psychiatric caseness at baseline	Adjustment for Baseline GHQ score	Adjustment for Spielberger Trait Anxiety Score
Low	2.46 (0.27)	3.53 (0.39)	2.85 (0.25)	3.07 (0.27)
Medium	3.57 (0.28)	4.54 (0.36)	3.29 (0.26)	3.50 (0.27)
High	4.48 (0.29)	5.20 (0.37)	3.54 (0.28)	3.69 (0.29)
F value	17.3	4.85	2.31	1.64
P value	0.0001	0.008	0.0994	0.1949

In the association with GHQ score measured prospectively there was no interaction between noise level and Weinstein sensitivity at baseline but as expected there was a powerful interaction between GHQ score at baseline and Weinstein sensitivity ($F = 68.0$ df 3,1129 $p<0.0001$). Because of the strong association between GHQ score and sensitivity at baseline it was difficult to separate the effect of noise sensitivity prospectively on GHQ score from the effect of the baseline GHQ score. This was attempted in several ways. In selecting men who were not GHQ cases at baseline, noise sensitivity had a significant predictive effect on GHQ score at follow up ($F = 5.12$ df 1,896 $p<0.024$). By adjusting for psychiatric caseness at baseline, but

using the whole prospective sample, a significant effect of Weinstein sensitivity on GHQ score prospectively was still found but this was much diminished when adjusting for total GHQ score at baseline (Table 2). The gradient was further diminished, though still present, after adjusting for Spielberger trait anxiety score at baseline. The association between sensitivity and GHQ score was further examined by constructing as a new outcome, a GHQ change score (GHQ score at baseline - follow up GHQ score). For the lowest tertile of sensitivity the mean GHQ change score was, 0.56(0.3) for the middle tertile 0.28(0.3), for the highest tertile - 0.65(0.3) $F = 5.46$ df 2,1129 $p<0.004$). This suggests that being high sensitive at baseline is associated with a fall in GHQ between baseline and follow up.

Discussion:

As in cross-sectional noise studies traffic noise level in this prospective study does not predict psychiatric disorder. However, there is an association between noise sensitivity at baseline and future psychiatric disorder. It can be argued that this study is not the final answer to whether noise causes psychiatric disorder for two reasons. First, these are only preliminary results which do not represent the whole sample and, secondly, the levels of traffic noise exposure are not especially high. Nevertheless, this finding is in keeping with the literature and these traffic noise exposure levels are likely to be typical of small town and rural populations.

Interpretation of the noise sensitivity findings is more difficult. Noise sensitivity alone predicts psychiatric disorder at follow up. Part of this association may be explained by the powerful association between noise sensitivity and GHQ score at baseline, that noise sensitivity may be indirectly measuring psychiatric disorder. Despite this it cannot be seen as a direct proxy for psychiatric disorder as the finding still remains after adjusting for psychiatric disorder at baseline. It may also be that total GHQ score is too rigorous a criterion for baseline psychiatric disorder and adjusting for this eliminates any association with subclinical symptoms. For, in previous studies, it is this subclinical level of psychological morbidity, measured by neuroticism of which noise sensitivity is an indicator (24, 25). After introducing the Spielberger trait anxiety score which measures stable negative affectivity, into the model, the effect of noise sensitivity is virtually eliminated again suggesting that noise sensitivity is tapping this level of morbidity.

Noise sensitivity is also a secondary symptom of depression which decreases as depression improves (32) and this is supported by examination of GHQ change scores where there was likely to be a fall in GHQ scores among high sensitive subject between baseline and follow up. Overall, noise sensitivity is an indicator of subclinical psychological morbidity and predicts psychiatric disorder at follow up. Noise sensitivity is not a specific risk factor for psychiatric disorder caused by traffic noise in this population. There is no evidence from this study, as with previous community surveys to suggest that environmental noise causes significant psychiatric morbidity.

Acknowledgements: Our grateful thanks are due to Ian White and Peter Sweetnam for statistical advice and to David Poor for data management.

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A dose-response relationship between cumulative noise exposure and hypertension among female textile workers without hearing protection

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ABSTRACT

Cumulative noise exposure (CNE) was investigated as a risk factor for the prevelance of hypertension in 1101 female textile workers using a logistic model. The results showed that CNE, which incorporates both dBA level and duration of exposure, results in a dose-response relationship with hypertension and, at the same time, reduces the high correlation between age and working years. Using a logistic model, the adjusted odds ratio (OR) for CNE was 1.033 ($p=0.034$) which was slightly higher than sound pressure level alone when noise exposure was represented by dBA and working years treated as independent variables. In the CNE model, the OR for age was 1.157 ($p<0.001$) versus 1.101 ($p=0.323$) in the alternative model. This finding supports the hypothesis that CNE may be a more appropriate measure of risk for hypertension due to exposure to continuous noise and it results in a model consistent with the known effect of age on hypertensive risk. The OR for parental hypertensive history and self-reported salt intake was very nearly equal between the two models. Using likelihood measures, the contribution of age showed three times the influence of noise exposure where parental hypertensive history and salt intake were 2.0 and 1.6 times more important than noise exposure.

Key words: cumulative noise exposure, dose-response relationship, hypertension, logistic regression model

INTRODUCTION

1101 female workers, who worked in a textile mill in Beijing, were the study subjects[1]. Each worked in a single workshop in this mill for their entire working life and all had worked in the mill for at least five years. Six workshops were selected because of the spatial uniformity of the SPLs within each and to cover the range of exposure levels in the mill.

The SPLs in each workshop were measured with Brüel and Kjäer sound level meters type 2300 and 1625. Eighty measurements were made at fixed points within the working area of the six workshops. Time-weighted average (TWA) exposures for workers in these shops were estimated and ranged from 75 to 104 dBA. The factory safety officer had conducted a noise

survey every two years and reported that the SPLs in each workshop have been essentially constant since production started in 1954. His noise data were consistent with those collected during this study. The SPL in a given workshop did not vary spatially by more than two dBA which resulted in a TWA exposure for all workers assigned to that shop essentially equal to the workshop mean. The noise spectrum was typical of textile mills and broad band in nature.

As might be expected with such a stable population, there is a very high correlation between age and years worked in the mill ($r = 0.966$). In order to avoid collinearity between age and working years, which had plagued an earlier analysis, cumulative noise exposure (CNE) was used to describe noise exposure[2]. CNE was defined as:

$$CNE = SPL + 10 \log (\text{work years}),$$

where SPL is the A-weighted constant sound pressure level. CNE measures the total acoustic energy of the noise exposure and is numerically equal to the SPL if the exposure duration is one year. Using this exposure index the workers were divided into four groups and the average age in each was calculated. The distribution of ages is different for the different exposure groups as determined by the F test with three degrees of freedom.

Table 1. Distribution of Age Among CNE Groups in Female Textile Workers

CNE : dBA	Number of Workers	Age : mean ± SD
80-89	188	32.3 ± 7.2
90-99	262	29.8 ± 6.2
100-109	385	36.4 ± 7.3
110-119	266	41.9 ± 7.8
Total	1101	35.5 ± 8.4

$F = 141.34$; $df = 3$; $p < 0.01$

Second shift workers were studied (2:00 PM to 10:00 PM). The measurement of blood pressure and the administration of a questionnaire were carried out between 1:30 and 4:30 PM and before the beginning of the day's work. All data were collected between 8 July to 10 August 1985. Blood pressure was measured by 10 medical students twice in sitting subjects by mercury sphygmomanometer after 10 minutes of rest. The students were trained so that readings differing by less 4 mmHg were achieved between the trainer and each student. If two readings on any worker differed by more than 4 mmHg in either systolic or diastolic pressure, measurements were repeated after further rest intervals until the difference met this criterion. The room in which the blood pressures were measured had SPLs below 60 dBA.

According to the recommendations of the World Health Organization Expert Committee[3], hypertension was defined as systolic pressure greater than or equal to 160 mmHg, or diastolic pressure greater than or equal to 95 mmHg, or both. Subjects were also classified as hypertensive if they were currently using antihypertensive drugs.

The questionnaire included identifying information, occupational history, hearing protection history, disease history, parent's hypertensive history and information regarding the subject's history of antihypertensive drug use. Also, data were collected on smoking and drinking habits and the worker's perception of their own use of salt in the diet in relation to their co-workers. This information was thought to be accurate because the workers routinely ate their meals in a common dining hall and many were aware of the dietary habits of their fellow workers. None of the workers used ear plugs during their work. Twenty one workers were smokers, three of whom were hypertensive, one exposed in 75 dBA and other two exposed to 90 dBA. Seven workers drank alcohol routinely. None were hypertensive. None of the workers reported that they had been diagnosed as hypertensive at the time they were first employed in the mill. Thirty two women were pregnant at the time of the study. None was hypertensive.

RESULTS

Seventy nine cases were found in the 1,101 female workers which results in a 7.2 percent prevelance of hypertension. Table 2 shows that the crude prevalence increased appreciably in the highest exposure group. To explore this association in detail, a logistic regression analysis

Table 2: Cumulative noise exposure and prevalence of hypertension in female textile workers

CNE dBA	Number hypertensives	Number of workers	Hyper. Prevalence: %
80-89	8	188	4.3
90-99	5	262	1.9
100-109	23	385	6.0
110-119	43	266	16.2
Total	79	1101	7.2

(model I) was carried out using hypertension, as defined above, as the binary outcome variable. A binary outcome was selected because the majority of hypertensives had been previously diagnosed and were on medication for this condition. The predictor variables were CNE, age,

salt use (low, normal or high) and a history of hypertension in either parent (presence or absence).

Table 3. Estimated parameters for logistic model I for prevalence of hypertension among 1101 female textile mill workers

Variable	Coefficient	SE	p-value	Odds Ratio
Constant	-12.08	1.64	---	---
CNE dBA	0.0323	0.0152	0.034	1.033
Age	0.1461	0.0205	<0.001	1.157
Salt (high)	0.0678	0.3140	0.829	1.070
Salt (normal)	-0.7991	0.4060	0.049	0.450
Family History	0.7763	0.2590	0.003	2.173

Table 3 contains the estimates of the coefficients of CNE, age, self-reported use of salt and parental hypertensive history. All are significantly associated with the probability of hypertension at above the 5% level. These results were compared with a second logistic model using SPL and working years as separate independent variables instead of merged into CNE. In this model (model II), the coefficient of SPL (Table 4) was essentially unchanged but working years and age were not significantly associated with hypertension. These results indicate that CNE serves the same purpose as SPL and working years when describing the dose response relation between noise exposure and hypertension and avoids the collinearity between the number of years worked and age.

Table 4. Estimated parameters for logistic model for prevalence of hypertension among 1101 female textile workers

Variable	Coefficient	SE	p-value	Odds Ratio
Constant	-10.61	2.07	---	---
SPL dBA	0.0303	0.0152	0.047	1.031
Age	0.0959	0.0626	0.126	1.101
Working years	0.0544	0.0551	0.323	1.056
Salt (high)	0.0569	0.3140	0.856	1.059
Salt (normal)	-0.8270	0.4080	0.043	0.437
Family history	0.7480	0.2600	0.004	2.113

The differences in the likelihood values for each predictor variable for hypertension between the two logistic models are compared in Table 5. The relative influence of CNE (4.728)

in model I was greater than SPL in model II. Likelihood values for age were very different; model I =14.407 ($p < 0.001$) and model II = 2.234 ($p = 0.135$). The likelihood value associated with salt intake and parental hypertensive history were nearly equal in both models. These results suggest that model I leads to a better representation of the data with CNE replacing SPL and working years. In model I the dose-response relationship between hypertension and CNE is maintained and the known influence of age is more adequately represented. Model I indicates that the contribution of age to hypertension is three times that of noise exposure with parental history and salt intake contributing 2.0 and 1.6 times that of noise respectively.

Table 5. Comparison of differences of maximum likelihood between logistic model I and Model II

	Logistic model I		Logistic model II	
Variable	DML	p-value	DML	p-value
SPL dBA	---	---	4.061	0.044
Working years	---	---	1.021	0.312
Age	14.407	<0.001	2.234	0.135
CNE dBA	4.728	0.030	---	---
Family history	9.274	0.002	8.520	0.004
Salt use	7.445	0.024	7.752	0.005

The goodness-of-fit of model I was assessed by contrasting the observed and predicted cases of hypertension in 24 strata using age and CNE as the predictor variables. The overall chi-square value was 28.04 which corresponds to $p = 0.14$. One stratum contributed 74% of the total with five observed cases and 0.836 predicted; otherwise the model predicts the observed data with a high degree of accuracy.

DISCUSSION

In our previous analysis of these data, we were unable to adequately explore the effect of duration of exposure on the prevalence of hypertension due to the collinearity of age and working years. In the foregoing analysis we approached this problem from a different perspective by adopting the same index of cumulative exposure traditionally used in studies of noise induced hearing loss, namely an index based on the equal-energy principle. The result of this change was to substantially decrease the standard error of the age variable, thereby making it the most important predictor of hypertensive prevalence in the new model versus its non-significant p-value in the older version. Hence, in the new model, the effect of age is consistent with that reported in the general literature on hypertension[4].

The effect of adopting CNE as a predictor of noise exposure showed only a small change in the coefficient, standard error and p-value in the logistic model when contrasted with those of the former model which used SPL only. The dose-response relationship is maintained and the fit is very similar. It is attractive to interpret these positive changes as evidence that the prevalence of hypertension is better predicted by cumulative noise exposure than by exposures over a shorter time period. For example, in our earlier analysis we interpreted the lack of a working-year effect as evidence that the effects of noise exposure were manifested within the first five years of exposure, that being the shortest duration of exposure among this cohort. While the new analysis is consistent with interpreting CNE as a more appropriate exposure-related variable, we note that the CNE index is a strong function of SPL and less sensitive to working years. For example, a 90 dBA exposure for five years gives a CNE of 97 whereas 90 dBA for 40 years yields a CNE of 106 because of the dependence of CNE on the log of working years. Therefore, if a third analysis was done in which working years was not used at all, and noise exposure based only on dBA, the results would be similar to those obtained using CNE including the improved description of the independent role of age.

The major result of our re-analysis then, is that the data on the Beijing textile mill workers is consistent with the possibility that cumulative noise exposure, as measured by the equal-energy principle, is a risk factor for hypertension. We cannot exclude the possibility, put forth in our former analysis, that other characteristics of noise exposure related to dBA levels over shorter period may be the more appropriate risk factor. A further elucidation of this issue is likely to require investigating the effects on hypertensive prevalence in cohorts exposed to intermittent or impulse noise.

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COMPARISON OF ACUTE REACTIONS AND LONG-TERM EXTRA-AURAL EFFECTS OF OCCUPATIONAL AND ENVIRONMENTAL NOISE EXPOSURE

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Abstract

Acute reactions to noise can be divided into direct and indirect reactions. Direct reactions are mediated by nervous and/or endocrine transduction without cortical intermediation. Indirect noise effects are mediated by noise-induced disturbances to various activities followed by cortical responses, including psychological stress reactions, and lead to physiological stress reactions. Occupational noise exposure causes acute increases of noradrenaline and/or adrenaline and blood pressure. Traffic noise exposure during several hours of lectures, which reduced the intelligibility of syllables but not of sentences, had similar effects. Other indirect noise effects are increases of total cholesterol and decreases of magnesium, a recently detected risk factor for angina pectoris and sudden cardiac death. The mechanism of elevated magnesium excretion involves a temporary increase of Mg in blood serum and results in a long lasting decrease of intracellular Mg, e.g. in erythrocytes, which was correlated to increases of blood pressure. Psychological effects of environmental noise exposure are usually accompanied by increases of noradrenaline or adrenaline. Nocturnal noise exposure, which alters the time pattern of sleep phases, causes stronger adrenaline increases than during the active phase. The combination of occupational noise exposure with traffic noise exposure at home causes increases of blood pressure and total cholesterol. Long-term extra-aural health effects of noise cannot be discussed on the basis of 24h -L_{eq} since the noise level, at which disturbance occurs, differs greatly from one activity to another. Noise-induced health effects correlate more closely to noise-induced disturbances of activities than to noise levels.

Our present knowledge about long-term extra-aural health effects is sufficient to substantiate the need for protection against noise exposure causing severe disturbances, in order to prevent health risks.

Introduction

This paper will compare acute and chronic effects of noise in order to examine a chain of argumentation concerning long-term extra-aural health effects.

Acute effects of noise can be studied in identical test persons by experimentally changing the noise exposure. This method has the advantage that the cause-effect relationship can be determined beyond doubt. Its disadvantage, however, relates to the quality and quantity of the effects. Under normal conditions of exposure, these effects lie within the normal range of variation for physiological parameters, such as blood pressure. How far the long-term repetition of such acute noise effects constitutes a health risk remains an open question.

On the other hand, epidemiological studies of groups subjected to different noise exposure over long periods offer the advantage that differences in morbidity rates can be examined.

However, the conclusion that these differences were caused by the differences in noise exposure is open to question. A synopsis of the two approaches might, therefore, be helpful.

Acute reactions to noise

Acute reactions to noise can be divided into two different types, direct and indirect reactions. Direct reactions to noise are mediated by nervous and/or endocrine transduction to different organs without cortical intermediation (Fig 1). Indirect noise effects, however, are caused by noise induced disturbances to various activities, provoking different types of cortical response, including psychological stress reactions such as tension, annoyance, etc.(Fig.2).

Direct noise effects are studied in laboratory experiments where the test persons have nothing to do but listen to the exposure while attached to a variety of instruments. These experiments may last one or two hours (1).

Indirect noise effects can best be studied in field experiments in real life situations with experimentally altered noise exposure. Even short-term experiments have shown that environmental noise causes annoyance and that annoyance causes physiological reactions such as increased heart frequency and vasoconstriction (2).

To investigate the correlation between direct and indirect noise effects on blood pressure, we used identical subjects in a laboratory experiment and a field study.

In the lab, the blood pressure of 41 men (aged 24-54 years) was measured at the end of 5 minutes at rest and at the end of 5 minutes of exposure via headphones to intermittent white noise L_{Amax} = 100 dB. In the field study, the same test persons took part in a seminar for 6 hours a day. Their blood pressure was measured once per hour. The first day of the seminar was held without noise exposure. On the second day, traffic noise, L_{Am} = 60 dB, was played back via loudspeakers to the seminar room. The effect of this noise was:

1. a reduction in syllable intelligibility but constant sentence intelligibility requiring greater concentration by the participants;
2. an increase in psychological tension in 20 men;
3. changes of 5 mm Hg or more in blood pressure: increases in 16 men and decreases in 5 men.

The group mean values for both experiments are listed in Tab. 1. In the lab, only diastolic blood pressure increased, whereas in the field both blood pressure parameters showed an increase. There was no correlation between the individual blood pressure reactions in the two experiments. The correlation analyses also showed that in the field experiment both decreases and increases in blood pressure correlated with psychological tension (3).

The main conclusion from this study is:

Direct noise effects do not correlate with indirect noise effects. It is wrong therefore to extrapolate the effects of low level noise exposure in real life situations from the effects of high level noise exposure in the laboratory.

Health effects of long-term noise exposure

We have to distinguish, therefore, between the health effects which may result from long-term repetition of direct noise effects and those from recurring indirect noise effects. Since indirect noise effects are much more pronounced than direct effects, and in real life the

combination of noise with other stressors quite often exceeds the individual tolerance level, causing stress reactions, we shall concentrate on acute indirect reactions to noise and their long-term health effects.

A field study on the effects of noise on performance and recreation examined, how the noise-induced increase in effort that was invested in work correlated with psychological and physiological reactions as well as the morbidity as a function of the frequency of noise events. Tab. 2 shows the correlation coefficients and Tab. 3 the noise-induced increase in morbidity (4). The increased morbidity seemed to be caused by stress at work and impaired recreation during breaks, both induced by road traffic noise.

In order to detect possible pathomechanisms of long-term noise exposure, we shall discuss briefly the results of three studies:

1. 57 men (aged 18-34 years) worked one day with and one day without exposure to motor-racing noise (L_{Am} = 85 dB, L_{Amax} = 100 dB) (5). The results are listed in Tab. 4.
2. 8 men and women (aged 18-40 years) who each slept in a laboratory for 8 nights, 4 nights without noise and 4 nights with flight noise (L_{Am} = 36-56 dB, L_{Amax} = 55-75 dB). The effects of noise on deep sleep and adrenaline (6) are shown in Fig.3.
3. 27 men (aged 35 - 54 years) worked one day with and one day without ear protectors (L_{Am} = 95 dB;ΔL = 13 dB).
   The blood pressure increase (syst./diast.) was 6.6 ***/ 1.2 mmHg(7).

In the first study we found the following acute noise effects:

1 -increase in adrenaline excretion
2 -blood pressure increase
3 -increase in Mg-excretion
4 -increase in total cholesterol.

From the adrenaline effects in study 1. and 2. we conclude:

Also during sleep the organism reacts to noise by increasing adrenaline excretion. This reaction is much stronger than in the active phase.

We will now consider acute blood pressure increases and the long-term risk for hypertension. Rose (8) measured the blood pressure of air traffic controllers during two days with an extremely difficult work load. He chose air traffic controllers because this is an occupation which carries a particularly high risk for hypertension. Tab. 5 compares the blood pressure increase induced by work load with blood pressure increases induced by different noise exposures. The comparison leads to the conclusion that persons exposed to noise at work are probably subject to an increased hypertension risk similar to that of air traffic controllers. This conclusion is consistent with the results which Dr. Zhao has just presented.

Noise-induced losses of magnesium may lead to long-term negative Mg-balance, indicated by a long-term decrease in the Mg-content of the erythrocytes. In a longitudinal traffic noise study we found a significant correlation between decrease in erythrocyte Mg and increase in blood pressure (9). The Caerphilly and Speedwell heart disease studies revealed a relationship between low Mg in blood and/or diet and angina pectoris and sudden cardiac death (10).

In a group of 255 men we investigated the combined effects of work noise and traffic noise (11) on blood pressure and total cholesterol. The results are shown in Fig. 4. Although the indoor level of road traffic noise seems negligible when compared to the work noise, it has a pronounced interaction effect. From this result we conclude that extra-aural health effects cannot be discussed on the basis of 24h-L_{eq}. The kind of activity being disturbed is an important factor. It is obvious that recreation and sleep are disturbed by much lower levels of noise than physical work.

Long-term health effects seem to correlate more closely with noise-induced disturbances of activity than with noise levels, as Dr. Babisch has mentioned. I would like to close with some preliminary results from a cohort study involving 1006 men and women. Data on working and living conditions, includi¬g noise, were collected by questionnaire and compared with self-reported diseases 11 years later (12). Some of the results are listed in Tab. 6. These results indicate that people who reported noise disturbances at work or at home show a higher morbidity, and that noise at home is especially dangerous to health if sleep is disturbed.

Our present knowledge about long-term extra-aural health effects is still limited and we need more and well-planned studies. However, our knowledge is sufficient to substantiate the need for protection against noise-exposure causing severe disturbances, in order to prevent possible noise-induced health risks. For the purposes of prevention particular importance should be attached to night time protection.

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Tables and Figures

Tab. 1 Comparison of blood pressure differences
- as a direct effect of 5 min. noise (L_{Amax} = 100 dB)
- as an indirect effect of noise-induced disturbance to communication (field study: L_{Am} = 60 dB, 6h)

	Blood pressure differences (mmHg) systolic	diastolic	n	
Lab. experiment	+ 1.1	+ 3.1***	41	Total group
Field study	+ 1.7*	+ 1.2*	41	Total group
	+ 3.5**	+ 2.0*	17	Noise-sensitive sub-group

*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$

Tab. 2 Correlation between noise-induced increase in effort and indirect noise effects (n=66)

Disturbed concentration	r = 0.77
Tension	r = 0.68
Fatigue	r = 0.67
Annoyance	r = 0.60
Headache	r = 0.44

Tab. 3 Rel. frequency of absence from work due to illness as a function of the frequency of clearly audible noise events at work (n=66)

Frequency of noise events	Rel. frequency of illness
extremely seldom and seldom	1
sometimes	1.13
often	1.25
very often	1.34

The trend is statistically significant: $p < 0.05$

Tab. 4 Effects of exposure to noise (L_{Am} = 85 dB) at work on various physiological parameters

	no noise	noise	% change
Excretions in urine collected over 8 hours:			
adrenaline (µg)	1.8	2.3**	+ 27%
magnesium (mmol)	1.56	1.79**	+ 15%
In blood samples:			
total cholesterol (mmol/l)	4.77	4.87*	+ 2%
average blood pressure			
systolic (mm Hg)	111.7	115.4***	+ 3%
diastolic (mm Hg)	73.0	74.8**	+ 2.5%

Tab. 5 Blood pressure changes induced by work load or noise

Work	Duration (h)	n	Change in exposure	Δ p sys. mm Hg	Δ p dia. mm Hg
air traffic control	8	123	high/low workload	4.3**	2.9**
seminar	6	42	60/40 dB(A)	1.7*	1.2*
soldering circuits	7	57	85/50 dB(A)	3.4***	1.8**
operating machines	8	27	95/82 dB(A)	6.6***	1.2

Tab. 6 Effects of noise disturbance at work or at home on self-reported 11-year morbidity in 1006 men and women

	Relative risk for	RR	(95% c.i.)
Noise at work	-myocardial infarction	2.78	(1.01/7.63)
Noise at home			
without sleep	-angina pectoris	1.01	(0.66/1.55)
disturbance	-hypertension	0.76	(0.47/1.23)
with sleep	-angina pectoris	1.86	(0.94/3.70)
disturbance	-hypertension	2.32	(1.16/4.65)

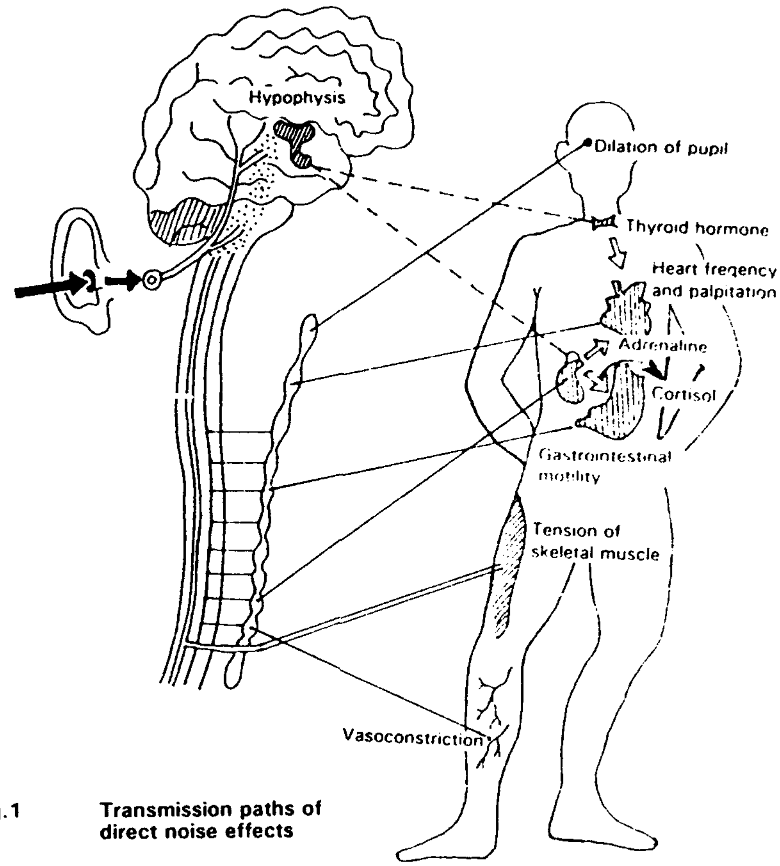


Fig.1 **Transmission paths of direct noise effects**

Noise	
Disturbance of - Communication - Concentration - Recreation...	Disturbance of activities
- Tension - Annoyance...	Acute psychological effects
- Endocrine reactions (Adrenaline, Noradrenaline) - Excretion of Magnesium - Gastrointestinal motility - Vasoconstriction - Tension of skeletal muscle..	Acute physiological effects
Increased risk for - Heart / Circulation - Gastrointestinal diseases...	Long-term health effects

Fig.2 **Reaction chain of indirect noise effects**

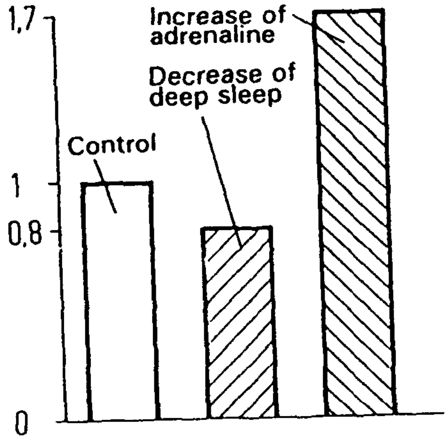
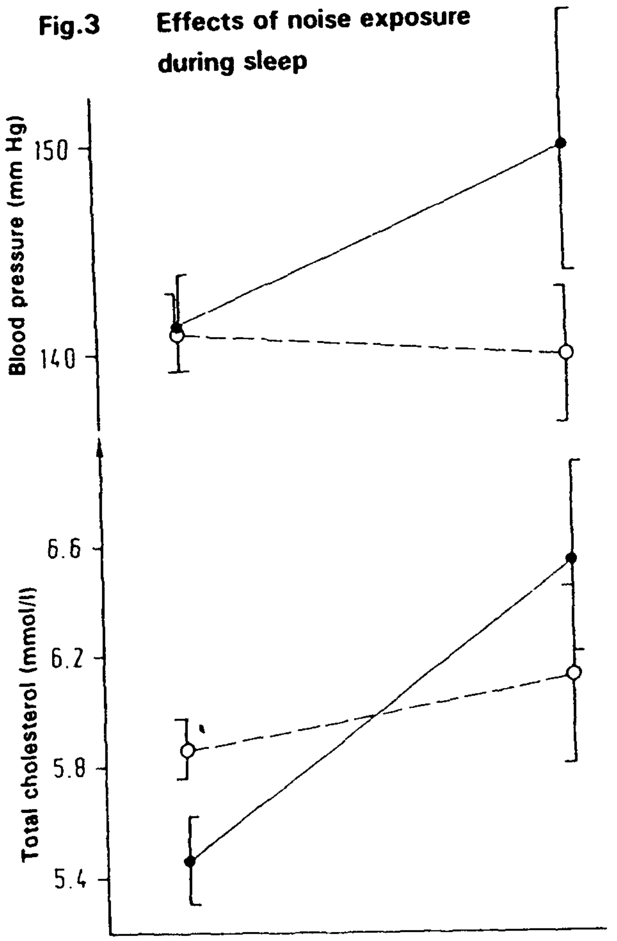


Fig.3 **Effects of noise exposure during sleep**



Traffic noise:
L_{Am} < 60 dB **L_{Am} > 60 dB**

Fig.4 **Effects of noise at work and traffic noise at home**
above: blood pressure (systolic)
below: total cholesterol
o---o noise at work L_{Am} < 90 dB
●—● noise at work L_{Am} > 90 dB
(mean values and s.e.)

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Nonauditory physiological effects of noise are premised on the belief that noise acts as a nonspecific stressor. As such, noise triggers a broad range of responses which are greatly influenced by personal characteristics of the individual and the presence of other stressors. Thus, it is not surprising that contradictory and ambiguous findings have been, and continue to be, reported from both experimental and epidemiological studies.

During the 1983-1988 period, most of the research focused on cardiovascular effects, especially blood pressure, probably because it is a major risk factor for other cardiovascular diseases and is relatively easy to measure without risk to subjects. Researchers were concerned principally with explaining disparate findings. Unlike earlier research, investigators controlled for major confounding variables such as age, obesity and family history of hypertension. It soon emerged that the more rigorous studies which adjusted for confounders were less likely to find an adverse effect. Other problems became apparent and recommendations centered around them. These included: 1) there was a predominance of cross-sectional studies, weak for determining cause; 2) noise exposure was not very precisely quantified; 3) individual characteristics such as perception of noise as a stressor and coping strategies in noise were seldom addressed; 4) most studies were conducted at noise levels above those recommended for hearing conservation; 5) certain groups, namely children, pregnant women, the sick, the elderly, the "noise sensitive or annoyed" could be more vulnerable to noise than others; 6) large numbers of subjects were required for epidemiologic studies; 7) the effect of total noise exposure from multiple sources had not been studied; 8) studies of physiological measures other than blood pressure were needed.

Unfortunately since 1988, the accumulation of evidence has not put to rest the controversy surrounding the effects of noise on blood pressure and cardiovascular disease. However, the few studies of industrial noise exposure have extended our knowledge and suggest opportunities for further determining the conditions under which occupational noise is harmful to health. A large cross-sectional study of textile workers in China demonstrated a dose-response relationship between extremely high noise (exceeding currently permissible limits in most countries) and blood pressure among women exposed for their entire working years without ear protection. Two studies from the USSR reported at the 1991 Minsk conference appear to substantiate this association. As noise control measures and use of modern hearing protectors are introduced into these and similar industries, prospectively designed before-after studies could, under ethical circumstances, provide more definitive information as to the effect of sound attenuation on nonauditory health effects. Such studies would also provide ideal opportunities for concurrently determining the role of noise in accidental injury causation.

Some progress has been made in the field of environmental noise. There are epidemiological studies now that directly relate the noise level (road traffic) to disease outcome (ischemic heart disease), which is currently the basic public health issue of interest. These studies are of reasonably high validity in terms of exposure and disease assessment and control for possible confounding variables, but lack from low precision due to small numbers in the higher exposed groups of subjects. Nevertheless, although of borderline statistical significance, the Caerphilly and Speedwell prospective studies and the Berlin population-based case-control studies give some weak evidence for a slightly increased cardiovascular risk in subjects who live on streets with daytime outdoor traffic noise levels of Leq above 65-70 dBA. There was some indication that these associations were more pronounced in subjects also exposed to noise at work. However, noise sensitivity did not seem to confer psychological vulnerability to traffic noise effects in the Caerphilly cohort. These studies confirmed the difficulty in accurately classifying the noise exposed, and the large sample sizes needed to obtain the statistical power necessary to detect a low risk while adjusting for confounders or stratifying for effect modifiers. Since large populations and considerable resources and effort will be required to quantify any nonauditory effects, future causal research might best be directed toward particularly vulnerable

groups rather than to the general population. However, no such vulnerable groups have yet been identified. Ultimately information based on the general population will be needed for community noise abatement decisions. As pointed out by Dr. Ising at the 1991 "Noise and Disease" conference in Berlin, weak effects due to traffic noise can be important to the public health since such large numbers of people are daily exposed to this noise source.

Results from studies of civilian aircraft noise and military low altitude flight noise are inconclusive; no increase in cardiovascular disease has been observed in recent and more methodologically sound research. Several studies indicate that the elderly and children may be especially vulnerable to acute reactions to low altitude flight noise and that children in high exposure areas may suffer from higher anxiety, but no greater number of medical problems than children from low exposure areas.

Other research presented at this conference reinforces the view that individual differences are responsible for establishing a person's response to noise, and this in turn, may shape the nature of the observed effect. At least one study showed that adaptive/coping behaviors to traffic noise were related to lower systolic and diastolic blood pressure. In an experimental study, noise sensitive subjects demonstrated greater physiological arousal and slower habituation to noise than less sensitive subjects. Findings were not entirely consistent across two sensitivity scales, suggesting the continued need for improvements in defining noise sensitivity.

Other researchers introduced non-cardiovascular outcomes which require attention in the future. There is some indication that long-lasting noise exposure at work may increase vulnerability to respiratory alterations. Although the evidence is far from conclusive, a few studies suggest that noise-induced stress can temporarily suppress the immune system. In view of the importance of the immune system to health, more laboratory research is needed on the role of noise relative to this health parameter. Short-term effects of noise on sleep include increased blood pressure, heart rate, vasoconstriction, endocrine reactions and change in respiration. Although at present it is questionable as to whether there can be long-term effects of such changes, with the increase in community noise it is not unreasonable to assume there may be impairment to health for some individuals.

While advances have been made since 1988, nonauditory health effects of noise remain inconclusive. Overall, it appears that noise at levels which protect hearing may protect against nonauditory effects of industrial noise, but this needs definitive testing. Traffic noise showing weak cardiovascular effects appear to be the community noise source which warrants greatest attention. In summary, the priorities for further research are as follows:

-improved characterization of individual noise exposure from multiple sources (home, work, leisure time activities, transportation)
-determination of the effects of sound attenuation on cardiovascular and other physiological outcomes. Ideally, this should be studied in a before-after design plus a control group, in industries which are introducing hearing conservation programs for the first time
-further attention to effect modifiers and their interactions
-prospective studies of community noise, especially road traffic noise, targeted to vulnerable groups and including a range of outcomes
-exploration of the role of disturbances to sleep from nocturnal noise on cardiovascular and other health outcomes
-laboratory/experimental studies of the role of noise on the immune and respiratory systems.

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Les effets physiologiques non-auditifs du bruit sont posés en principe sur la conviction que le bruit agit comme un stresseur non spécifique. En tant que tel, le bruit déclenche une grande série de réponses qui sont largement influencées par les caractéristiques personnelles de l'individu et la présence d'autres stresseurs. Ainsi, il n'est pas surprenant que des résultats contradictoires et ambigus ont été, et continuent d'être exposés dans les études expérimentales et épidémiologiques.

Durant la période 1983-1988, une grande partie de la recherche s'est concentrée sur les effets cardio-vasculaires, en particulier la tension artérielle, certainement parce qu'elle est un facteur de risque principal pour d'autres maladies cardio-vasculaires et est relativement facile à mesurer sans risque pour les sujets. Les chercheurs étaient principalement soucieux d'expliquer des résultats disparates. Contrairement à la recherche de la période précédente, les enquêteurs ont contrôlé les principales variables de confusion telles que âge, obésité et antécédent d'hypertension dans la famille. Il apparu vite que les études les plus rigoureuses qui rectifiaient les confusions trouvaient probablement moins d'effets contraires. D'autres problèmes devinrent apparents et des recommandations étaient centrées autour d'eux.

Ceux-ci comprenaient :

1) il y avait une prédominance d'études transversales, trop pauvres pour déterminer la cause ;
2) l'exposition au bruit n'était pas quantifiée très précisément ;
3) les caractéristiques individuelles telles que la perception du bruit comme stresseur et les stratégies de lutte contre le bruit étaient rarement écrites ;
4) la plupart des études étaient effectuées à des niveaux de bruit au-dessus de ceux recommandés pour la protection de l'audition ;
5) certains groupes, en particulier les enfants, les femmes enceintes, les malades, les personnes âgées, les "sensibles au bruit ou les gênés" pourraient être plus vulnérables au bruit que les autres ;
6) de nombreux sujets étaient nécessaires pour les études épidémiologiques ;
7) l'effet de l'exposition totale à plusieurs sources de bruit n'a pas été étudié ;
8) des études de mesures physiologiques autres que la tension étaient nécessaires.

Malheureusement depuis 1988, l'accumulation de preuve n'a pas arrêté la polémique autour des effets du bruit sur la tension ou les maladies cardio-vasculaires. Toutefois, les quelques études sur l'exposition au bruit industriel ont étendu notre connaissance et constituent des observations pour déterminer davantage les conditions sous lesquelles le bruit professionnel est nuisible à la santé. Une grande étude transversale des ouvriers du textile en Chine a démontré une relation dose-réponse entre un bruit extrêmement élevé (dépassant les limites actuellement admissibles dans la plupart des pays) et la tension des femmes exposées pour toutes leurs années de travail sans protection aux oreilles. Deux études

soviétiques présentées à la Conférence de Minsk en 1991 semblent justifier cette association. Comme les mesures du contrôle du bruit et l'usage de protecteurs auditifs modernes sont introduits dans ces industries ou celles similaires, les études avant-après éventuellement conçues pourraient, en respectant une certaine éthique, fournir des informations plus définitives comme l'effet de l'atténuation du bruit sur les effets non auditifs de la santé. De telles études pourraient aussi fournir des occasions idéales pour déterminer simultanément le rôle du bruit dans la causalité de blessure accidentelle.

Des progrès ont été faits dans le domaine du bruit environnemental. Il y a maintenant deux études épidémiologiques qui rapprochent franchement le niveau de bruit (circulation routière) à la conséquence de la maladie (maladie cardiaque ischémique), qui est actuellement le sujet d'intérêt fondamental en santé publique. Ces études ont une validité raisonnablement élevée en fonction de l'exposition et de l'évaluation de la maladie et du contrôle des variables possibles de confusion, mais manquent de précision à cause des faibles échantillons de sujets les plus exposés. Néanmoins, malgré la signification statistique limite, les études de Caerphilly et Speedwell et les études du contrôle de cas de la population vivant à Berlin donnent une faible preuve d'un risque cardio-vasculaire légèrement en hausse chez les sujets qui vivent sur des rues avec des niveaux de bruit de circulation extérieure en journée de Leq au-dessus de 65-70 dBA. Il y a quelque indication que ces associations sont plus prononcées chez les sujets également exposés au bruit pendant le travail. Toutefois, la sensibilité au bruit ne semblait pas conférer la vulnérabilité psychologique aux effets du bruit de circulation dans la cohorte Caerphilly. Ces études ont confirmé la difficulté à classer précisément l'exposition au bruit, et d'avoir des échantillons de grande taille, suffisants pour obtenir la force statistique nécessaire à détecter un faible risque pendant que l'on mettait au point les facteurs de confusion ou que l'on stratifiait l'effet des atténuations. Puisque de vastes populations et de considérables ressources et effort seront demandées pour quantifier les effets non-auditifs, une future recherche causale devrait être mieux dirigée vers des groupes particulièrement vulnérables que vers la population d'ensemble. Toutefois, de tels groupes vulnérables n'ont pas encore été identifiés. Finalement l'information basée sur une population d'ensemble sera nécessaire pour les décisions de réduction du bruit dans la communauté. Comme l'avait signalé Dr Ising à la conférence "Bruit et Maladie" de Berlin en 1991, les effets faibles dus au bruit de circulation peuvent être importants pour la santé publique car beaucoup de gens sont quotidiennement exposés à cette source de bruit.

Les résultats des études sur le bruit d'avions privés et le bruit d'avions militaires à basse altitude sont peu concluants : on n'a observé aucune augmentation de maladies cardio-vasculaires dans une recherche récente et plus solide méthodologiquement. Cependant plusieurs études montrent que les personnes âgées et les enfants pouvaient être particulièrement vulnérables à des réactions aiguës au bruit de vol à basse altitude et que les enfants des zones à haute exposition pouvaient souffrir d'une plus grande anxiété, mais pas de plus nombreux problèmes médicaux que les enfants des zones à basse exposition.

Une autre recherche présentée à cette conférence renforce l'opinion que les différences individuelles sont dignes de confiance pour établir la réponse au bruit d'une personne, et ceci en retour, pourrait influencer la nature de l'effet observé. Une étude au moins a montré que les comportements d'adaptation ou de lutte au bruit de circulation étaient liés à une tension systolique et diastolique inférieures. Dans une étude expérimentale, les sujets sensibles au bruit ont montré une plus grande stimulation physiologique et une plus lente accoutumance au bruit que les sujets moins sensibles. Les résultats n'étaient pas entièrement

logiques parmi deux échelles de sensibilité, suggérant le besoin continu d'améliorations pour définir la sensibilité au bruit.

D'autres recherches présentèrent les conséquences non cardio-vasculaires qui demandent une attention dans le futur. Il y a quelque indication qu'une exposition au bruit de longue durée au travail peut augmenter la vulnérabilité à des altérations respiratoires. Bien que la preuve soit loin d'être définitive, quelques études suggèrent que le stress dû au bruit peut déprimer temporairement le système immunitaire. Par rapport à l'importance du système immunitaire pour la santé, on a besoin de plus de recherche en laboratoire sur le rôle du bruit sur ce paramètre de santé. Les effets du bruit à court-terme sur le sommeil comportent une tension en hausse, le rythme cardiaque, la vasoconstriction, les réactions endocrines et un changement respiratoire. Bien que maintenant il est mis en question de savoir si de tels changements peuvent avoir des effets à long-terme, avec l'augmentation du bruit de la communauté il n'est pas illogique de présumer qu'il pourrait y avoir une altération de la santé chez quelques individus.

Bien que des avances aient été faites depuis 1988, les effets non-auditifs du bruit sur la santé restent peu convaincants. En général, il apparaît que le bruit à des niveaux qui sauvegardent l'ouïe peuvent protéger des effets non-auditifs du bruit industriel, mais ceci nécessite un examen décisif. Le bruit de circulation montrant des effets cardio-vasculaires faibles semble être la source de bruit de communauté qui requiert une plus grande attention. En résumé, les priorités pour la recherche future sont les suivantes :

- caractérisation améliorée de l'exposition individuelle au bruit à partir de sources multiples (logement, travail, activités de loisir, transport),
- détermination des effets de l'atténuation du bruit sur les conséquences cardio-vasculaires ou physiologiques autres. D'une manière idéale, ceci devrait être étudié dans un projet avant-après plus un groupe de contrôle, dans des industries qui insèrent des programmes de protection de l'audition pour la première fois,
- plus d'attention sur les facteurs modifiants les effets et leurs interactions,
- études éventuelles du bruit de la communauté, particulièrement du bruit de circulation, visant les groupes vulnérables et incluant une série de conséquences,
- exploration du rôle des gênes du sommeil provenant du bruit nocturne sur les conséquences cardio-vasculaires et conséquences sur la santé,
- études en laboratoire/expérimentales du rôle du bruit sur les systèmes immunitaire et respiratoire.

RECENT ADVANCES IN THE STUDY OF NOISE AND HUMAN PERFORMANCE

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Abstract

The effects of noise on human performance depend on the type of noise, characteristics of the person exposed to the noise and the nature of the task. Research in this area has decreased over the last five years but there have been important re-evaluations of our current knowledge of the topic and major developments in at least two areas, namely the effects of irrelevant speech and the combined effects of noise and other factors. Future research must aim to move from the laboratory to study the effects of noise in real-life settings. In addition, further consideration must be given to understanding the mechanisms underlying the various effects of noise.

Introduction

A tribute to Donald Broadbent

I would like to begin this article by acknowledging the enormous contribution to the study of noise and performance made by Donald Broadbent, who died earlier this year. Donald worked on the effects of noise on performance for forty years and his contribution is well-documented in his various papers on the topic. In addition, he inspired numerous other researchers and provided a framework for assessing both the practical implications of the effects of noise and the mechanisms underlying these phenomena. His impact will be felt for years to come and the present review uses the type of approach that Donald applied to the area. Donald will be sadly missed and fondly remembered and future generations will continue to benefit from his excellent work.

Published research on noise and performance in the last five years.

It is not my intention to give an exhaustive account of the studies carried out in the last five years. However, I believe that it is important to give an overview of the amount and type of research that has been carried out. If one considers one specific type of literature search (PSYCHLIT: keywords - noise and performance) one finds that there were 28 papers published between 1982 - 1987 and only 16 papers in the last five years. Similar outcomes are found if one uses other databases and keywords. The type of paper has also changed, with there being a reduction in the number of experimental studies and an increase in the reviews of the area (e.g. Smith, 1989; Smith, 1990a; Smith & Broadbent, 1991; Smith & Jones, 1992). However, other important areas of research have developed and many of the papers on these do not appear in a "noise and performance" search. The area, therefore, should not be thought of as in decline. Rather, there has been a detailed re-evaluation of traditional topics which has led to a better idea of the more robust noise effects. In addition, two relatively new areas, the effects of irrelevant speech and the combined effects of noise and other factors, have received much more attention than was previously the case.

A general framework for examining the effects of noise and performance.

Smith and Broadbent (1991) concluded that the effects of noise on performance are complex and depend on (1) the nature of the noise (2) the nature of the task, and (3) characteristics of the person exposed to the noise. Such a view has important implications for the approach to the topic, both from an applied and theoretical viewpoint. For example, if one is trying to consider safe levels of noise exposure where there will be no risk to safety or performance efficiency one cannot focus on a single parameter such as the intensity of the noise, rather one must consider a range of noise parameters and also ask who is doing what type of activity in the noise. Such a situation clearly makes legislation difficult. From a research point of view the general view outlined here suggests that one should consider all of the above factors in our studies. There is a gradual move to such research, although it is clearly more expensive and complicated than the older studies where performance of a group of subjects on a single task was examined at two noise intensities. Given that there have been few "ideal" studies how should one organise research in the area? Again, the approach of Donald Broadbent is useful here in that he initially sub-divided studies into field and laboratory research. This will be used here and each section will be organised so that the position in 1988 is summarised, new developments described and proposals for future research suggested.

Field studies

Accidents

The position in 1988:
There is evidence both from cross-sectional comparisons (e.g. Cohen, 1974) and intervention studies (e.g. Cohen, 1976) that noise may be a contributory factor in the occurence of accidents.
New research:
No new work has been carried out on the relationship between noise exposure and accidents.
Future research:
It is essential that more prospective studies are carried out, and that the effects of interventions which do not change the working environment, other than reducing the noise level, are assessed. Analysis of individual accidents must also determine whether these can be attributed to auditory (e.g. masking) or non-auditory (e.g. attentional) effects of noise.

Productivity

Position in 1988:
Noise may impair aspects of performance efficiency but have little effect or even facilitate others. For example, Levy-Leboyer & Moser (1988) found that noise impaired tasks involving high mental load and control precision, had no effect on manual dexterity, and improved performance of tasks involving physical strength.
New work:
Again, there has been no work to suggest that the above view should be changed.
Future research:
It is clearly essential to determine which tasks are unaffected by different types of noise and which ones are sensitive. However, laboratory research suggests that a "task taxonomy" of noise effects may be difficult to produce.

Community studies.

Position in 1988:
The clearest data has come from studies of the performance of school children (e.g. Cohen et al., 1980) which have shown that exposure to aircraft noise produces impairments in the cognition and motivation of the children.

New and future research:

This topic is covered in the next paper by Hygge, Evans & Bullinger.

Office noise

This is a relatively new topic and clearly requires consideration of a variety of noise sources, e.g. irrelevant speech, machine noise, building noise and outdoor noise sources. The effects of irrelevant speech are briefly summarised later in the paper and given more detailed coverage by Jones & Macken. In general, one may conclude that there is evidence that office noise impairs performance and that this comes from two main sources:

(a) Subjective ratings given by office workers.

(b) Noise impairs office type tasks in the laboratory.

Future research must examine whether such impairments are obtained in the actual performance of workers in offices. Similarly, appropriate intervention studies must be conducted. An initial study has been carried out looking at performance when office noise is masked by white noise (Loewen & Suedfeld, 1992). The results showed that a no-noise group performed better than either masked or unmasked office noise groups. However, the masked noise subjects performed better than those exposed only to the office noise, and the masked group also felt more aroused and less disturbed or stressed by the environment.

Laboratory studies of moderate intensity noise

A general feature of research over the last fifteen years has been a switch from the study of psychomotor tasks to tasks involving the processing of verbal materials. This will be illustrated by considering three areas: sustained attention, selective attention and strategies of performance in noise.

Cognitive vigilance.

Position in 1988:
Performance of detection tasks involving memory and the processing of verbal materials is impaired by moderate intensity (70-75dBA) noise (Jones et al. 1979).
New work:
The above results have been confirmed by a number of studies (e.g. Smith, 1988a; Smith, Thomas & Brockman, 1993) using different versions of the cognitive vigilance tasks.
Future research:
Studies are now needed which consider the effects of different types of noise on such tasks. Similarly, individual differences in the effects of noise must be examined. It is also essential to determine which mechanisms are involved in these noise effects.

Selective attention.

Position in 1988:
Noise may influence aspects of selective attention, although effects vary depending on the nature of the task (see Smith & Jones, 1992).
New research:
Smith (1991, 1993) confirmed the selective effects of noise using two tests developed by Broadbent, which consider many aspects of attention in the same tasks. A global effect of noise was found (i.e. an effect which generalised across different types of noise and was found for the group as a whole) with noise increasing the difference between focussed attention and categoric search tasks. In addition, Smith (1993) reports other effects which were specific to certain types of noise or only found for sub-groups of individuals.
Future research:
A new project is considering the role of central noradrenalin in the changes in attentional selectivity in noise (Nutt & Smith, in progress).

Strategies of performance in noise.

Strategy choice:

There is now considerable evidence showing that subjects performing in noise may use different methods of doing the task to those used by subjects in quiet (see Smith & Jones, 1992).

Inflexibility in noise:

Smith (1990b) had subjects carry out a dual task (a proportion estimation task and a running memory task) in which the difficulty, probability and priority of the two tasks changed rapidly. The results showed that performance of the running memory task was impaired in noise, which probably reflects an effect of noise on the ability to change the method of doing the task.

Resource allocation in noise:

Smith (1988a, 1990b, 1990c) has examined resource allocation in noise by studying dual task performance. The difficulty of each task was varied, as was the probability of having to do the task, and in other conditions one of tasks had a higher priority than the other. Different combinations of tasks were used and in some cases the two tasks competed for common resources, whereas other tasks were performed passively and were not influenced by the nature of the other task. The results can be summarized as follows:

1. The effects of noise depended on the nature of the task, with tasks that were performed in an active manner being impaired by noise, whereas a proportion estimation task showed little effect.
2. Changing task parameters may influence the noise effect if the two tasks compete for common resources. For example, when a running memory task was paired with a cognitive vigilance task (a detection of repeated numbers task) then the effect of noise was modified by changes in the task parameters. When there were no priority instructions, the cognitive vigilance task was impaired by noise, but this effect was removed when it was made the high priority task.
3. The effects of noise depended on whether the task parameters were constant or were rapidly changing (this has already been mentioned in the section on inflexibility in noise).

The results in these sections show that several views of noise and performance have been confirmed by recent studies. Before considering two areas which have really only been of interest for a relatively short period another traditional area, individual differences in the effects of noise on performance, will be reviewed.

Individual differences in the effects of noise on performance.

Demographics

Age:

Hambrick-Dixon (1986) found that noise impaired the psychomotor performance of five-year-old children whereas other types of performance showed an interaction between previous exposure to noise and noise conditions (i.e. children from noisy schools were better in noise, whereas those from quieter schools were impaired by noise). Some studies of the elderly have found that older subjects show greater impairments in noise than younger subjects (Lahtela et al., 1986). However, Harrison & Kelly (1989) found no differences in the effects of noise on performance of young and old subjects, although the older subjects did show increased cardiovascular activity in noise.

Gender:

Gulian and Thomas (1986) found that noise reduced the pace at which female subjects worked but had little effect on the rate of male subjects. However, other studies (e.g. Edmonds and Smith, 1985) have found no sex differences in the effects of noise, and others suggest that other factors, such as time of day (Loeb et al., 1982) may modify sex differences in the effects of noise on performance. However, Smith and Miles (1987) found no evidence of noise, time of day and gender interactions.

Personality

Results from studies of the effects of noise on cognitive tasks suggest that neuroticism and anxiety levels are important in determining individual differences in response to noise. Neurotic subjects appear to be impaired to a far greater extent than stable subjects and those high in trait anxiety have also been shown to be very vulnerable to noise (Smith, 1988b).

There has been considerable interest in the role of individual differences in noise sensitivity in determining response to noise. This is dealt with in detail in the free communications of this conference, and I will, therefore, merely make a methodological point here. Measures of noise sensitivity are highly correlated with neuroticism and any claims for the importance of noise sensitivity must take account of the possible confounding influence of neuroticism.

Areas of new research

The free communications section of this conference deals with many other topics which have received coverage before (e.g. the role of effort; noise and driving; noise and vibration; noise and sleep; effects of noise on performance in the classroom; noise after-effects). Two areas which only started to receive attention recently are the effects of irrelevant speech and combined effects of noise and other factors. These will be briefly outlined here as they receive detailed coverage in other papers.

Effects of irrelevant speech

Earlier studies of this have been reviewed in detail by Jones & Morris (1992). Some of the major results can be briefly summarised as follows:

1. Several studies (e.g. Colle and Walsh, 1976; Salamé and Baddeley, 1982) have shown that performance (ordered recall) is impaired if speech (but not white noise) is played while a subject learns and remembers verbal materials.
2. The effect of the irrelevant speech is independent of its intensity, certainly within the range 55-95 dB(A).
3. The meaning of the speech is unimportant in that effects may be obtained with foreign languages, with nonsense material and backwards speech.
4. The effect appears to be on memory rather than perception.
5. Vocal music has a greater distruptive effect than instrumental music, but this is not found if the vocal component is hummed. This demonstrates that the words have to be articulated in order to disrupt performance.
6. The susceptibility of working memory tasks to disruption by irrelevant speech suggests that reading, with its reliance on memory, may also be impaired. Jones (1990) has reviewed a series of experiments on the effects of irrelevant speech on proof-reading and the results showed some similarities to the short-term memory effect (e.g. the effects appeared to be independent of intensity). However, there were also some differences, in that the meaning of the speech was very important.
7. These recent studies of irrelevant speech have important practical implications in that, as the effects are independent of intensity, one would have to reduce levels by several tens of decibels to eliminate such problems.

More recent developments in this area will be described by Jones & Macken. However, two methodological issues will be raised here. First, it is crucial when one studies meaningful noise to determine whether the effects generalise across materials. This requires the appropriate design and analyses. Secondly, experiments must examine whether effects are short-lived or will be present even with repeated exposure to the noise and/or task.

Combined effects of noise and other factors.

Recent work into combined effects of noise and other factors has examined noise and (1) alcohol (2) caffeine (3) time of day, and (4) viral infections, as well as more traditional areas such as noise and vibration. It is clearly the case that one should not consider noise in isolation without considering the host of other factors which may modify its effects. Initial research on a topic tries to control for the possible effects of other factors and yet in the real-life situation it is going to be the combination of factors which produce a particular outcome. Indeed, one need is for some appropriate modelling of the relationships between factors which can then be tested in multi-factorial studies. The results obtained are of great practical relevance. For example, Smith, Thomas and Brockman (1993) have shown that while noise may have little effect on the reaction times of healthy individuals it will greatly impair the speed of subjects with a common cold. The major problem with examining combined effects is that such studies are generally purely descriptive and there is a lack of a good theoretical basis.

Mechanisms underlying the effects of noise on performance.

The previous section has described an area where our research must aim to try and explain what underlies the various effects of noise on performance. In the past noise effects have been explained in terms of arousal, distraction, increased load/effort, strategic effects, and in terms of specific changes in functions (e.g. the effects of irrelevant speech on the articulatory loop). Many of these approaches will need to be refined or replaced by views which not only account for the findings but can generate further predictions to be tested in future studies.

Conclusions

(1) Although the volume of work on this topic has decreased important advances have been made in two main areas, namely the effects of irrelevant speech and combined effects of noise and other factors.

(2) Other traditional topics have been studied as well and we now have a better idea of the more robust noise effects.

(3) Two main areas clearly require much further work:

- (a) There is a need to move from the laboratory to real-life settings.
- (b) Further consideration of the mechanisms underlying the various effects of noise is required.

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THE MUNICH AIRPORT NOISE STUDY: PSYCHOLOGICAL, COGNITIVE, MOTIVATIONAL, AND QUALITY OF LIFE EFFECTS ON CHILDREN

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ABSTRACT

Before the shutdown of the former Munich International Airport in May 1992 and the inauguration of the current one, children were recruited into one experimental and one control group at both the old and new airports. The two experimental groups are comprised of the children at the old airport that were exposed to high levels of aircraft noise, and the children who are exposed at the new airport. The two control groups were matched to their respective experimental groups on the basis of sociodemographic characteristics.

On two consecutive days before the change over of airports, 396 children, aged 9 - 12, were tested individually in 1.5 hr sessions in an air-conditioned and sound attenuated trailer. Measures included overnight urinary catecholamines and cortisol, resting and reactivity measures of cardiovascular functioning, calibrated indices of annoyance to different noise sources, speech discrimination against different noise backgrounds, reaction time under noise and quiet conditions, visual search, running-memory span, long-term memory, performance on a standardized reading test, a Glass and Singer noise aftereffect trace test, perceived noise and environmental quality in the residential setting, and standardized quality of life indices.

Data analyses for the first measurement wave at the old airport showed that children in chronic aircraft noise exposure have elevated stress hormones and a general perceptual adaptation to noise. On long-term recall and language skills there was impairment in the chronically aircraft exposed children that grew progressively stronger with increased difficulty of the material. The aircraft exposed children also persisted less on challenging puzzles. Chronic aircraft noise exposure effected environmental perception and an emotional component in quality of life. Cardiovascular measures are currently being analyzed.

Thus, different sets of effects of chronic noise exposure have been shown. Quality of life is impaired and stress hormones are elevated. In auditory, perceptual tasks there is a general adaptation to noise. On cognitive tasks requiring more central processing, such as memory and reading, there are deficits associated with chronic noise exposure. Motivation to persist on challenging puzzles appears to be impaired as well by chronic noise.

A second measurement wave finished early 1993 and two additional measurement waves are planned.

The shutdown of the former Munich International Airport in May 1992 and the inauguration of the current one at the same time have provided an unprecedented opportunity to investigate in a longitudinal, prospective design the psychophysiological, cognitive, motivational, and quality of life effects of noise exposure on children. The broad, long-term objective of this research program is to understand how chronic environmental stress from aircraft noise affects children

Beginning in the fall of 1991, before the change over of airports, children at both sites were recruited into experimental and control groups. The two experimental groups are comprised of the children at the old airport that were exposed to high levels of aircraft noise, and the children who are exposed at the new airport. The two control groups, one for the former airport and one for the new one, were selected from areas that were not and will not be exposed to much aircraft noise. The two control groups were matched with their respective experimental groups on the basis of sociodemographic characteristics. One wave of data collection occurred prior to the changeover in airports. A second measurement wave ended in March 1993, and two further post-changeover data collection waves are planned.

On two consecutive days close to 396 children aged 9-12 years, were tested individually for 1.5 hr each day in a specially designed air-conditioned and sound-attenuated trailer. The trailer has four closed booths which can accommodate a child and an experimenter. Each booth is equipped with headphones, automated blood-pressure and pulse monitors, a reaction-time unit, various response-buttons, signal lamps and a fold-up desk for paper and pencil tasks. Headphones, signal and response buttons in all booths are computer-integrated in the control room of the trailer.

OVERVIEW OF DEPENDENT MEASURES: PSYCHOPHYSIOLOGY, COGNITION, MOTIVATION, AND QUALITY-OF-LIFE

Four sets of dependent measures were chosen for tests and mini-experiments in the trailer:

Psychophysiological measures included overnight urinary catecholamines and cortisol. Resting and reactivity measures of blood pressure and pulse were taken several times in noise and quiet. The collection of both resting neuroendocrine and blood pressure data will enable us to examine several interesting hypotheses. For example, although there is preliminary evidence that chronic airport noise exposure is associated with elevated blood pressure (Cohen et al., 1986; Evans, 1990), no prospective data exist on this important issue. Furthermore although the blood pressure associations in children living in noisy areas are believed to be due to a stress mediated response, up to now no one has been able to examine the neuroendocrine pathway in this response. We expect that noise elevates chronic, circulating catecholamines such as adrenaline and noradrenaline and that these, in turn, heighten resting blood pressure.

We will also examine adrenocortical activity which we believe will be elevated especially among those children most annoyed by noise. To our knowledge, no data exist on the relationship of chronic noise exposure and reactivity. Increasing attention has been given to the potential role of reactivity to stressors in the cardiovascular system as a central mechanism in the apparent link between stress and coronary heart disease (Krantz & Manuck, 1984). We will examine children's blood pressure and pulse elevations in response to tasks such as reaction time both under quiet and noisy conditions. We expect differential reactivity as a function of chronic noise exposure.

The **cognitive** measures included an audiometric screening task with 12 tones of 1000 Hz presented at the lowest audible level the computer could produce (around 30 dBA). A noise annoyance, master scaling procedure was adopted from Berglund et al. (1987) and Berglund & Nordin (1990). The master scaling procedure is designed to deal with the problem that each individual's criterion for perceived annoyance with community noise is somewhat idiosyncratic. Concepts such as *very annoyed* or *not at all annoyed* may mean different things to different people. In particular, we are interested in the question - does chronic exposure to noise alter children's judgment criterion for annoyance with community noise. In our version of the annoyance master scaling, the children were first trained outside the trailer to use a magnitude estimation procedure. Each child was asked to jump as far she/he could from a standing position and was informed that this jump equals a 100 on the scale. The starting line and the 100 line was marked on the ground. Next, the child was asked to jump half way to the 100 line and was told this amounted to 50. The numerals 10, 25 and 75 were trained to mastery in the same way. During the actual exposure to

noise stimuli in the trailer, children were asked to jump with their fingers on a 200 mm scale. The children were presented with three replications, each consisting of 15 noise stimuli with a duration of 4 sec. The 15 stimuli were of three kinds and of 5 sound levels. Pink-like, broad-band noise was played back at 42, 54, 66, 78, and 90 dBA L_{eq}. Aircraft and road traffic noise were presented at 45, 55, 65, 75, and 85 dBA L_{eq}. To minimize range effects, a wider range of pink noise intensities was used (cf. Berglund et al. ,1987). After each of the three replications three questions about community noise were asked. Those were: (1) what is the annoyance level you experience from the outdoor environment during an ordinary lesson in your classroom? (2) what is the annoyance level you experience from the outdoor environment during an ordinary dinner at home? and (3) what is the greatest level of annoyance you have ever experienced from an airplane flying over you outdoors? The master scaling procedure takes advantage of the fact that all subjects have been presented with the same set of pink noise bursts. Thus, both the annoyance ratings to the aircraft and road noise as well as the ratings of the three community noise situations can be expressed in their raw form or in a master scale where the individual's ratings of the pink noise constitutes the common reference.

A computer controlled signal-to-noise task was designed to map the procedure in Hygge et al. (1992), to assess speech discrimination against different noise backgrounds. A passage of a story was read from a tape-recorder against a silent background and the children were instructed to choose a comfortable listening sound-level by pushing "+" and "-" buttons. The level chosen defined the L_{eq}-level at which segments of non-fluctuating pink-like broad-band noise, and fluctuating aircraft and road noise were subsequently played in the background. In the foreground the story continued, but the sound-level of the voice reading the story dropped at random 10 dBA. The children were instructed to readjust the level of the voice with the + and - buttons, to the subjective criterion that they could understand what was said if they concentrate. One reason for employing this task, was the finding by Cohen et al. (1986) that long-term noise exposed children were less able to discern the best signal-to-noise ratio in a similar task.

In a reaction time task, the children were presented with random sequences of red and green lights. The correct response was to press one of two buttons when the red light came one and the other button when the green light came on. Two 5 min. sessions were run with each child. The first session in silence and the second one in 85 dBA L_{eq} fluctuating aircraft noise.

The running memory task consisted of strings of consonants presented over headphones at the rate of one per second. Randomly, the sequence was stopped and the children were asked to recall as many consonants as they could in the correct position. This task is sensitive to acute noise (Hamilton et al., 1977).

An easier version of an embedded figures' task, known to be sensitive to ventilation noise (Hygge, 1991a) and chronic stress (Baum et al., 1983) in adults was used. The children were presented a page with twelve figures. On the top row, five simple figures were presented, and the task was to pick out which one of the five simple figures were embedded in the complex ones.

A long-term recall test and a scoring manual was developed for a text on the Amazon jungle. On day one the children read the text in intermittent noise with perceived control (see the Glass & Singer task among motivational measures), and on day two they were tested in silence for recall with open-ended questions. This test was adapted from Hygge (1991b) who reported impairment of one week long-term recall in children exposed to 15 min acute aircraft and road noise.

A standardized German reading test was used (Biglmaier, 1969). The children read paragraphs of increasing difficulty. Speed and different types of errors were scored. The children were also given three word lists of increasing difficulty. Some of the words were fictitious, but could be pronounced according to the German pronunciation rules. The word lists were also scored for speed and different types of errors. This task was chosen because prior research has uncovered associations between chronic noise exposure and reading deficits, but all of those studies are cross-sectional (Evans, 1990; Evans & Lepore, in press).

With regard to **motivation**, a few preliminary results indicate that chronic exposure to environmental stressors, such as noise that are uncontrollable, may render children more susceptible to control-related deficits associated with the learned helplessness phenomenon (Seligman, 1975). Children from crowded homes, for example, are more vulnerable to the induction of helplessness by a pre-treatment of an insoluble puzzle in comparison to their uncrowded counterparts (Rodin, 1976). Children attending schools near airports are more likely to fail to solve challenging jigsaw puzzles and give up a more often during the short interval available for working on the puzzles (Cohen et al., 1986).

We will examine the potential importance of control in the motivational responses of children chronically experiencing aircraft noise by exposing children to acute aircraft noise (85 dBA L_{eq}) during a task. The children are instructed that they can turn off the noise if necessary, but it is suggested that we would prefer they not do so. Thus, perceived control is induced. Following the 15 minute task experience with perceived control over noise, children are given two line tracing puzzles. In these puzzles the task is to trace over lines without doubling back that connect different sports (e.g., soccer, basketball). Children are encouraged to work on each puzzle until they solve it or decide they cannot do it and then move on to the next puzzle. As in the Glass and Singer (1972) aftereffects paradigm, the first puzzle is insoluble and the second soluble. Persistence on the insoluble puzzle is measured. In addition we also probe for attributions for task performance. We expect that chronically noise-exposed children will attempt fewer insoluble puzzles. and to make more attributions for poor performance to internal, stable explanations such as ability (Abramson, Seligman, & Teasdale, 1978). Children from quieter areas are expected to attribute their performance to task difficulty.

The effects of noise on mood and quality of life are important indicators of the clinical-psychological impact of chronic stress. Quality of life is a construct referring to a person's self-assessed well-being and function in the emotional, physical, social and every-day life domain. The construct has been increasingly employed in medicine, in the area of clinical trials, and is now viewed as a fruitful approach to study the impact of stressors in general, including environmental stressors (Bullinger & Hasford, 1991). In the present study we employed a standardized children's one-dimensional mood measure, the Lewis scale (Lewis et al., 1984) and a newly developed German questionnaire (Bullinger et al., in press) assessing the four domains emotional, physical, social and every-day life (KINDL). The Lewis questionnaire was filled out while in the trailer, and the KINDL questionnaire was filled out at home together with a questionnaire on environmental perception.

The overall **rationale** for this study includes several specific and unique features: (1) It is a prospective study of non-auditory noise effects on the same children over several years. No such study has been reported. (2) The removal of the noise at the old airport affords us the opportunity to assess whether any of the initial differences between aircraft-noise exposed and non-exposed will diminish over time. Thus, it will be possible to assess whether any impairment from chronic aircraft noise exposure is permanent or reversible. (3) The time perspective with four measurement waves over five years provides the opportunity to compare and detail rate of change between and within different psychophysiological, cognitive, motivational and quality of life functions. (4) The multi-methodological approach, covering psychophysiology, cognition, motivation and quality-of-life, sets the pre-requisites for formulating and testing models of how those four areas are interrelated. (5) By studying the interaction between chronic noise stress and experimentally introduced acute noise stress from different noise sources, any inter-dependency between them can be assessed as well as selectivity or generalization to noise sources other than aircraft noise. (6) By testing all the children in silence and not in their everyday noise environments, any confounds with acute performance effects of noise are ruled out. (7) Finally, by collection of careful noise measurements in different locations around the airports, we can begin to model in a preliminary manner, dose-response functions between noise and different outcomes.

RESULTS AND DISCUSSION

Financial restraints made it necessary to give priority to data collection over data punching and analyses. Therefore, in the present paper we only present data from the first collection wave. Also, the space limits for this paper do not allow any details in comparing the experimental and control groups at the new airport, so results are restricted to children in the old airport's experimental and control groups at the time when the old airport was still operating. It should be noted that the analyses presented here are preliminary.

Several specific hypotheses about any differences between the aircraft-noise exposed experimental group and the non-exposed control group at the old airport were formulated and tested.

Our own noise-measurements with a Brüel & Kjær Community noise level analyzer for a number of 24 hr periods during data collection showed higher dBA L_{eq}-levels in the old airport experimental (OE) group than in the control (OC) group, ($M_{OE} = 68.1$, $M_{OC} = 59.2$). The dBA-sound levels exceeded 1% of the time showed the same difference ($M_{OE} = 79.8$, $M_{OC} = 69.0$).

The children in OE- and OC-groups did not differ on age ($M_{OE} = 10.69$ years, $M_{OC} = 10.86$, $t(129) = 1.56$, $p > .10$). On the sociodemographic variables, people in the OE-group more often than people in the OC-group lived in a house rather than in an apartment and more often owned than rented their dwelling, χ^2s$(1, N = 124) = 7.97$ and 11.4, $ps < .005$. These differences were due to people in the OE-group having lived for a longer time in their area, ($M_{OE} = 15.5$ years, $M_{OC} = 11.1$, $t(124) = 2.76$, $p < .01$). There were no differences ($ps > .1$) between the two groups in living area in m^2, number of rooms, number of persons in the dwelling, number of children and number of persons per room. Education, measured as years of schooling for the parent that followed the child to the experiment, did not differ. The parents' occupations were ranked in three status-groups (e.g., 1 = architect, dentist, civil engineer, 2 = nurse, clerk, teacher, 3 = manual laborer, secretary, shop-assistant). A fourth group for no profession given and a fifth group for students were added. There were no difference between the OC- and OE-groups on the frequencies observed in the five groups, $\chi^2(4, N = 116) = 4.96$, $p > .10$. Thus, OE- and OC-groups are reasonably matched and comparable on sociodemographic characteristics.

The neuroendocrine data showed no difference between the OE-and OC-groups in cortisol ($M_{OE} = 3.62$ µg/hr, $M_{OC} = 3.75$ µg/hr, $t(120) < 1$). For nor-adrenaline and adrenaline there were the expected differences of more stress hormones for the chronically noise exposed OE-group ($M_{OE} = 1108.82$ ng/hr, $M_{OC} = 766.22$ ng/hr, $t(120) = 3.43$, $p < .001$ and $M_{OE} = 526.36$ ng/hr, $M_{OC} = 368.62$ ng/hr, $t(120) = 2.89$, $p < .01$, respectively). The elevated catecholamines fit laboratory results indicating heightened adrenomedullary activity during stress (Evans & Cohen, 1987).

Blood pressure data have not yet been analyzed.

The screening for hearing impairment did not yield any significant difference between the OE- and OC-groups. On the raw uncalibrated values in the annoyance scaling of pink, aircraft and road noise, there were no significant effects involving the experimental and control groups. In a second step the log-values of the annoyance scores for aircraft and road noise were projected on each person's linear regression line for the pink noise which yielded a calibrated annoyance measure in pink noise units. An ANOVA showed a borderline effect of Groups, $F(1,133) = 3.24$, $p < .10$, and of the interaction Groups x Type of noise x Level $F(4,130) = 2.08$, $p < .10$, indicating higher values to the road noise in the OC-group than in the OE-group at the 65 and 75 dBA L_{eq}-levels, but no difference between the groups for aircraft noise of the same levels. This suggests some generalized adaptation to noise in the OE-group.

The raw annoyance ratings to the community noise questions about annoyance levels during an ordinary lesson in the classroom, an ordinary dinner at home and the greatest level of annoyance ever experienced from an airplane flying over you outdoors, showed a marginal effect of Groups,

$F(1,132) = 3.03$, $p < .10$, indicating more annoyance in the OE-group than in OC-group across all three items. After converting the raw values to pink noise units (se above), the effect of Groups became significant, $F(1,132) = 4.71$, $p < .05$. Lastly, after projecting the pink noise units on the regression equation for the both groups combined, the effect of Groups again was significant, $F(1,132) = 3.87$, $p = .05$. In neither of the three analyses of annoyance ratings were there any interaction with type of noise, which indicates that overall the OE-group reported more annoyance than the OC-group to all three items.

In the signal-to-noise task there were no differences between groups in the dBA-level chosen for comfortably listening to the story. When the background noise was introduced, children in the OC-group preferred a higher signal-to-noise ratio ($M_{oe} = 6.81$, $M_{oc} = 10.87$, $t(1,103) = 1.78$, $p < .05$, one-tailed). The ratio chosen varied with noise source, $F(2,102) = 113.33$, $p < .001$, to the effect that the non-fluctuating pink-noise background yielded the highest ratio, fluctuating road noise the second highest and fluctuating aircraft noise the least. However, the difference between the noise sources did not interact with Groups. That is, adaptation to noise in the OE-group was not specific to aircraft noise, but rather a general adaptation to noise from different sources. Thus, there are signs of generalized adaptation to noise on the auditory, perceptual tasks.

The were no significant differences between the two groups on the reaction-time task, neither in time to correct or incorrect answer, frequency of errors, with or without very short (< .1 sec.) and very long latencies (> 1.2 sec.). Nor was there any main effect of Noise ($t < 1$).

On the embedded figures' task were no differences between groups. The running memory task has not yet been analyzed. On the long-term recall task, children in the OE-group performed worse than those in the OC-group, ($M_{oe} = 4.54$, $M_{oc} = 5.76$, $F(1,130) = 4.55$, $p < .05$). Number of text-lines read in the aircraft noisy, perceived control, acquisition phase on day one, was almost identical in the two groups. Thus, the chronically aircraft noise exposed children were less proficient in the overnight recall of the text, and this effect was not dependent upon different degrees of distraction as measured by number of text-lines read. The results have a strong parallel in studies reported by Hygge (1991b) and in the present conference on long-term recall and *acute* exposure to aircraft noise. Chronic noise exposure in the old airport experimental group impaired cognitive faculties as suggested by attentional overload theory (Cohen et al, 1986). We don't know to what extent the effect on long-term recall interacted with perceived control and noise exposure in the induction phase. We suspect that the chronically noise exposed would be more negatively affected by acute noise exposure than the control group, and that perceived control would be a stronger counter-active measure for the control group.

On the German reading test not all children completed all the 12 paragraphs, but there was no difference between groups in how many they did complete, nor were there any difference in average time per paragraph, or total time on test. Total number of errors were higher in the OE- than in the OC-group, ($M_{oe} = 50.8$, $M_{oc} = 41.3$, $t(127) = 2.02$, $p < .05$, one-tailed). This difference remained significant when the number of paragraphs read on number of errors was co-varied out, $t(126) = 1.97$, $p < .05$, one-tailed. For the children who finished at least 8 out of the 12 trials, there was a significant interaction Groups x Number of trials $F(7,112) = 2.37$, $p < .05$, to the effect that with increasing number of trials, and thus increasing difficulty, the gap in errors increased to the advantage of the OC-group.

On the three word lists of increasing difficulty, there were no differences in how much time the two groups devoted to each list, and with the exception of two all children completed the three lists. Number of errors on the third and most difficult of the word lists was higher for the chronically noise exposed group than for the control group, ($M_{oe} = 7.10$, $M_{oc} = 4.57$, $t(125) = 2.10$, $p < .05$), but they did not differ on the first and second list.

The patterns of results that emerge from the reading test and word list test are identical. There is no difference between groups in time spent on the paragraphs and word lists, but with increasing difficulty of the task the advantage of the OE-group over the OC-group grows progressively

stronger. As argued above in relation to the long-term recall task, the problem facing the chronically noise exposed is not a matter of speed in intake of information, but rather an impairment of cognitive faculties as suggested by the attentional overload theory (Cohen et al, 1986). Our results are also consistent with the pervasive findings of stress effects on complex but not simple tasks (Evans & Cohen, 1987).

In the *Glass & Singer aftereffect* task, children in the OE-group made, as predicted, significantly fewer attempts to solve the insoluble first puzzle ($M_{oe} = 5.18$, $M_{oc} = 5.98$, $t(110) = 1.71$, $p < .05$, one-tailed).

With regard to mood and quality of life there were no significant differences between the OE- and OC-groups on the Lewis scale. The emotional component subscale of the KINDL-questionnaire showed lower scores for children in the OE- than in the OC-group, $M_{oe} = 27.8$, $M_{oc} = 30.1$, $t(118) = 2.47$, $p < .02$. No other differences between the groups were found for the other KINDL sub-scales. On the environmental perception questionnaire children in the OE-group reported their environment as less favorable than those in the OC-group on annoyance from aircraft noise, $M_{oe} = 8.57$, $M_{oc} = 1.78$, $t(124) = 15.57$, $p < .001$. Thus, aircraft noise had some impact on environmental perception and on the subscale tapping emotional components.

CONSLUSIONS

(1) Children exposed to chronic aircraft noise have elevated adrenaline and nor-adrenaline levels. (2) On tasks with a strong auditory input-component (annoyance rating, signal-to-noise) there is some general adaptation to noise in the chronically aircraft noise exposed group. That adaptation is general across noise sources. (3) On non-auditory, non-reading tasks (embedded figures, choice reaction time) there are no effects of chronic aircraft noise exposure. (4) On tasks that rely heavily on memory and reading (long-term recall, the German reading test and word lists), there is an impairment with chronic noise exposure. This impairment grows progressively stronger with increased difficulty of the material. Thus, there are different sets of effects of chronic noise exposure. In the auditory, perceptual tasks, there is adaptation to noise. On cognitive tasks requiring more central processing, such as memory and reading, there are deficits associated with chronic noise exposure from aircraft. (5) Motivation to persist on challenging puzzles appears to be impaired as well by chronic noise.exposure (6) Chronic aircraft noise exposure effected environmental perception and an emotional component in quality of life.

ACKNOWLEDGMENTS

We are grateful to a great number of persons and agencies for their help, but there is not space enough to thank them all. There is however, a very special group of people we want to thank for their foresight and efficient actions on our initial time-pressured proposals to get the necessary funds to prepare and start the study, including building the trailer. A special thanks therefore to Sirkka-Liisa Paikkala, The Nordic Noise Group, Kjell Andersson, The Nordic Traffic Group and The Swedish Environmental Protection Agency, Nils Antoni, The National Swedish Institute for Building Research, Ulla Torsmark, The Swedish Environmental Protection Agency, Thomas Lindvall, The Nordic Scientific Group for Noise Effects, and the Society for Psychological Studies of Social Issues. Support also came from N.I.H. grant 1R01 HL 4732-01A.

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VOICE POLLUTION: AUDITORY DISTRACTION AND COGNITION

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Abstract

Recent developments in the study of the effect of extraneous speech on task performance are reviewed. Interest is focused on the effects of memory, especially short-term memory. Two main themes are addressed: those characteristics of the task that render the person susceptible to this type of distraction, and those characteristics of the sound which make it disruptive. Those tasks that require keeping track of the order of events seem to be most at risk and this is true of both verbal and non-verbal memory. Non-speech sounds are as disruptive as speech sounds but in both these cases, the important characteristic is the degree of variation in the sound. Some implications for abatement arise from this work.

Résumé

Cet article réexamine les développements récents résultant d'une étude sur l'effet de la parole accessoire sur l'exécution d'une tâche. Les effets de la mémoire se trouvent au centre d'intérêt, surtout la mémoire à court terme. Deux thèmes principales se sont adressés: les caractéristiques de la tâche qui rendent la personne sensible à cette forme de distraction, et les caractéristiques du son qui le rendent perturbateur. Les tâches qui demandent à suivre l'ordre des évènements semblent être en plus de danger, ce qui est vrai pour la mémoire verbale aussi bien que pour la mémoire non-verbale. Les sons sans paroles sont aussi perturbateurs que les sons articulés, cependant dans ces deux cas le degré de variation du son est la caractéristique importante. Quelques implications pour la suppression résultent de cette recherche.

One consequence of the computer revolution is that the nature of work has changed considerably. A defining characteristic of work in modern offices is that its main component is mental rather than physical, involving the processing of verbal material (words and numbers), and is usually undertaken in surroundings of relative quiet. Although in terms of intensity the level of noise is low, evidence has emerged from laboratory studies that speech is especially intrusive and may disrupt the efficient performance of mental tasks, especially those involving memory. The suspicion that mental work may be disrupted by 'voice pollution' is reinforced by complaints about intrusive speech in the office setting. Our paper is a review of recent laboratory work which attempts an analysis of the findings with the aim of discovering those tasks that are most susceptible to disruption and those sounds that pose the greatest danger to efficiency.

One of the first indications that speech, even at levels as low as 50 dB(A) is disruptive appears in by the now classical work of Colle and Welsh (1976). They found that speech disrupted the short term recall of lists of letters. These effects of irrelevant speech arise in conditions that have two important features, first, that the to-be-remembered lists of letters were presented visually so that the effect of extraneous speech was not one of acoustic masking, and second, experimental subjects were told specifically to ignore the speech, the effect therefore is most likely beyond the control of the person. A number of features of the effect were explicated in subsequent work by the same group, particularly that the effect was not due to the meaning of the speech since roughly the same amount of disruption occurred with speech the subject did not understand. Perhaps the most

significant feature for the present context is that the effect seems to be independent of the intensity of the sound, at least within the range 40 to 70 dB(A). Above all else this has practical consequences since it implies that the speech has to be attenuated to the level of inaudibility before the damage to performance is countered. Achieving attenuation of this magnitude is, of course, technically demanding and as a result is prohibitive in terms of cost. However, recent work suggests that there may be other solutions and these will be discussed below.

In this present paper we will discuss the effects of irrelevant speech in detail. First we discuss how the sound interferes with information processing, with the aim of understanding which mental functions are most susceptible to disruption which in turn should suggest which jobs might be most at risk. Then we go on to discuss which sounds are most likely to be disruptive, to discuss whether there are physical characteristics of the sound that are primarily responsible for the effect.

Which tasks are susceptible to disruption?

Early on in the research into the phenomenon of irrelevant speech two explanations were put forward for the effect. One was due to Donald Broadbent (Broadbent 1982) which suggested that the interference occurred at a relatively peripheral level, whereby the verbal material to be memorised was presented, speech would compete for entry to later stages of processing. The disruption by sound was at the point where the visual material was encoded. In contrast, Salamé and Baddeley (1982) suggested that the effect was not at encoding but in memory, after the visual and auditory material had been registered and gained entry into the information processing system. Recent results show that both these approaches are correct, but only under very highly constrained circumstances (see Jones and Morris, 1992 for a review). From the point of view of the original serial recall task used by Colle and Walsh (1976) it is safe to assume that Salamé and Baddeley (1982) are right and the disruption occurs in memory. This can be demonstrated in several ways. In this type of memory task it is usual to distinguish between the encoding stage when the to-be-remembered lists of verbal items are presented, and the rehearsal stage, in which the items are held in memory by a process of rehearsal, usually by repeating the list over and over to oneself for a period prior to recall. In the encoding stage the person registers the item while at the same time rehearsing any preceding items in the list. First, if the exposure to irrelevant speech is timed so that it is presented either at the encoding stage or at the rehearsal stage, we find that disruption of roughly similar magnitude occurs in both these cases. Logically therefore, the effect cannot be due to encoding alone (see Miles, Jones and Madden, 1991).

On the basis of this evidence alone we might expect that disruption by irrelevant speech might occur with any verbal memory task. However, the effect is rather more specific. All the early research used tasks that involved serial recall, that is, tasks in which the set of verbal items to be remembered (usually letters or digits) were well known to the person in advance, the critical feature of the task is that they have to be remembered in a specific order and only when an item is reported in the same ordinal position as it was presented can the item be scored as correct. A number of experimental findings now suggest that this particular characteristic, that of remembering serial order, is the one that determines whether the task will be disrupted by speech. For example, Salamé Baddeley (1990) found no effects with a task in which the items were words that could be remembered in any order. Both Morris and Jones (1992) and Jones and Macken (1993a) found that remembering a missing item from a well know set (for example, giving a list of six days of the week and asking the subject to report one which was missing) is not disrupted. No memory for order is required in this version of the task. If instead the person is prompted with one of the items from the list and is then asked for the item that followed it in the list, now tapping knowledge of serial order, the disruptive effect of speech is once again found.

In this sense of being confined to memory for serial order, the effect is rather more restricted in scope than was originally thought. However recent work emerging from our laboratory shows that in another sense the effect is more general in that the effect occurs with spatial tasks as well as verbal tasks. Spatial tasks are ones that require knowledge of the position of objects in space,

information which may be relayed by either visual or auditory signals. In the form of task used by us, a series of seven dots is presented, one at a time on the screen; this is followed by an interval, usually of ten seconds, in which the person holds these positions in memory; finally, all the dots are re-presented, this time simultaneously, and the job of the person is to mark the order in which the dots appeared (Jones, Morris, Farrand and Stuart, 1993). Just as for the verbal task, the person's response is scored in terms of order. In this type of task irrelevant speech produces significant degrees of disruption, as much as is usually found with a verbal task. We may show that with a spatial task also, in which there is no requirement for serial recall, for example, when the person sees all the dots at once and recalls them in any order, there is no effect of irrelevant speech (Morris and Jones, submitted).

This result is important in helping us understand the disruption by irrelevant speech. Primarily, it rules out any explanation of the effect that involves processing in the brain that is devoted exclusively to verbal material. One explanation of this sort is due to Salamé and Baddeley (1982, 1989). Their theory has two stages: the first stage is a filter that excludes non-speech sounds. This explains the finding that continuous white noise of moderate intensity has a very insubstantial effect on serial recall, but the effect of speech is very marked (we shall return to this point later). Of more relevance to the current theme of our discussion is the action of the second stage, in which the speech is present in memory alongside the verbal material that the person is trying to rehearse. According to their view, a difficulty arises in selecting the correct response from the items available in memory, the presence of auditory material makes the retrieval of the visually-presented material more difficult, particularly if they are similar in phonological content (Salamé and Baddeley, 1982). However, our results with spatial memory pose a difficulty for this explanation. If confusions occur in memory between things that sound alike, then dots and syllables should show minimal confusion, however they do show effects rather similar to those found when what is seen and what is heard are syllables. This suggests that some other factor is at play.

To summarize the arguments thus far; the primary characteristic of memory tasks that are vulnerable to disruption by irrelevant speech is that they require memory for serial order, moreover, they can be verbal or spatial. But we have said little about the characteristics of noise that make disruption more likely, a topic to which we now turn.

Characteristics of the Sound

From very early on in the investigation of this topic it has been assumed that speech had some special power to be disruptive. However, empirical evidence on this point is rather slim. We have already noted that continuous noise failed to produce an effect like irrelevant speech. The model of Salamé and Baddeley (1982, 1989) specifically confers a special status to speech by way of its filter that only passes speech or 'speech-like' material. But is speech necessary or sufficient? Indeed, is the term 'irrelevant speech' and in turn 'voice pollution' a misnomer?

Speech is not sufficient. Under certain circumstances speech does not produce the classic disruptive effect. Disruption does not occur when the speech sound (a single pitch pulse) is synthesized so that it is continuous even when it contains small changes in amplitude (Jones, Madden and Miles, 1992) so the mere presence of a signal with the spectral features of speech is not sufficient. Moreover, even if the sound is discontinuous, interspersed regularly with silence, it fails to be disruptive if it does not change in composition. For example, a repeated utterance ('ah') fails to produce any disruption, but a sequence of different speech sounds, ('bah', 'dah', 'lah') produces the usual degree of disruption (Jones et al., 1991). Additionally, if the same syllable is repeated but at different pitches (usually within an octave) it is disruptive (Jones and Macken, 1993a). Therefore, the effect is not produced by the mere presence of speech, rather, there has to be some element of change in the auditory stream before the effect occurs, an effect we have dubbed the 'changing state effect' (Jones, Madden and Miles, 1991). But, of course, this could be an effect of the second stage of Baddeley and Salamé's model, because the particular sounds used in the

studies just described were not sufficiently similar to the material in memory. Our scepticism about the status of speech is reinforced by the conclusion that speech is not necessary either.

Speech is not necessary. Do non-speech sounds produce effects similar to those of speech? It now appears to be the case that non-speech sounds are disruptive as long as they show some change in the short term, that is, they show changes in state. This can demonstrated by comparing the effect of changes in pitch of speech and non-speech material within the auditory stream. In order to do this we match the degree of change in pitch in a syllable ('ah') with that of a series of tones. As before, the contrast is made between tones or syllables that change, with a repeated tone or a syllable repeated at the same pitch. The fact that in these cases changing state tones give rise to the same amount of disruption as changing state speech (Jones and Macken, 1993) suggests that speech does not have special status. Not that all non-speech sounds that show some change, for instance, in spectral content produce disruption. Continuous, slow, randomly-varying pitch-glides do not, but if they are interrupted regularly by silence, then disruption is quite marked (Jones, Macken and Murray, 1993). This may be because the silence breaks up the glide into separate units that form a succession of discrete changing state units. In some circumstances this may occur without silence, the rate of change of energy in a continuous glide may at times be sufficient to lead to the perception of discontinuity and this may be a sufficient basis on which to produce units that change in state (see Walsh and Diehl, 1991).

Recently, we have been exploring the possibility that noise bursts produce effects akin to those of speech. Again, the important qualifying point is that the bursts have to form a changing state sequence; that is, the disruption occurs if we use a sequence of bursts with band-pass noise of different centre frequencies and not when the same burst is repeated (Jones and Macken, 1993b).

The finding that speech is neither necessary nor sufficient suggests that the 'irrelevant speech effect' is a misnomer. Rather the phrase 'auditory changing state effect' seems more appropriate. But the major implication is that performance is vulnerable to disruption to a wider range of sounds than was suspected hitherto. At the same time, the finding that non-speech sounds are disruptive further undermines the second stage of the Salamé and Baddeley (1982, 1989) model. By showing that sounds that bear very little relation to the contents of memory (at least in terms of its phonology) nevertheless produce disruption, the basis of the second stage becomes questionable.

These studies suggest that the relation of the phonological contents of what is heard to what is being rehearsed in memory seems to be of little consequence for performance. Evidence from studies in which the relation between the heard and seen streams is manipulated directly, reinforces the conclusion. If the person hears sounds identical to those that are in the to-be-remembered list that is being rehearsed, then the degree of disruption is no more than if the sounds are very different to those contained in the list (Jones and Macken, 1993b, Experiment 1). It has been demonstrated that similarity *is* important, but only *within* the auditory stream: a stream of sound containing a stream of phonologically similar words ('care', 'dare', 'fair', 'share' etc.) is less disruptive than one containing phonologically dissimilar words ('cow', 'hat', 'pen', 'bill', etc.) but the relation of these words to the material being rehearsed in memory does not determine the degree of disruption (Jones and Macken, 1993c).

Other evidence converges on this issue of similarity, supporting the importance of changes within the auditory stream while suggesting, further, that the organisation of the sound is important. It is now well established that a range of factors contribute to partitioning of the auditory scene into a series of elements or objects that are extended over time (see Bregman, 1990). Among these, spatial location seems to be among the strongest cues to organisation of sound into 'streams'. We may use this tendency to organise on the basis of spatial location, coupled with our knowledge of the effects changing state, as a supplementary test of the idea that the relation of what is heard and what is to be remembered is not important. The contrast is between stereophonic and monaural presentation of a repeated fixed sequence of three syllables. In the stereophonic case one syllable is assigned to the left ear, another is assigned to the right ear and the other syllable is assigned to both

ears. At the particular rate of presentation employed, the person has the experience of hearing three streams of sound — left, right and centre — each with a repeating syllable. The exact same sequence may be presented monophonically: in this case the person has the experience of a changing sequence of syllables from a single spatial location. That is, these two manipulations correspond to two levels of changing state; one, the monaural condition in which changing state is high, and the other, the stereophonic condition, in which changing state is low since in this case the subject experiences three sources of unchanging sound. Notice that in each case the phonological composition of the sound presented to the person is the same regardless of the mode of presentation and therefore its relation to what is being remembered remains constant. When the effect of these two types of organisation is compared, the monophonic has a greater disruptive effect than the stereophonic condition. Once again the effect of changing state seems to be the crucial factor, rather than the phonological composition *per se* (Jones and Macken, 1993d).

Conclusions

Two conclusions seem to have emerged from this work: the first is that mental activities involving the preservation of order in memory are at very great risk from disruption by extraneous sound. An important qualification to early work is that the tasks at risk may be verbal or non-verbal. The second conclusion is that non-speech sounds produce effects that have hitherto been considered only to be under the dominion of speech. The important feature here is the changing state of the sound, some change in its spectral composition or timing over the short-term for example, seems to be enough to produce the effect. At the same time the effects of changing state suggest a range of circumstances in which the effect of sound will be less and in turn suggest a method of abatement. In particular in relation to speech one of the consequences of changing state is that as the number of speakers increases the degree of disruption will actually diminish: as the number of voices contributing to the babble increases, so the distinctiveness of what is in each voice diminishes, particularly if the number of voices increases beyond the power of the ear to resolve them by spatial position. Work from the laboratory of Jurgen Hellbrück shows this to be the case (Hellbrück and Kilcher, personal communication). Somewhat counter-intuitively therefore one solution to the disruptive effect of speech is to introduce more of it, or a masking sound that masks out short-term fluctuations.

These findings have also served to suggest that the effect is more general than was previously thought, that they extend to non-verbal tasks and to non-speech sounds, which means in practical terms that there will be more mental work at risk from disruption.

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EFFECTS ON MENTAL TASKS INDUCED BY NOISE RECORDED AND PRESENTED VIA AN ARTIFICIAL HEAD SYSTEM

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Abstract

In this paper, we will first, present a theoretical framework for research concerned with the effects of binaurally heard background noise on mental performance. Hereby, we argue for a stronger inclusion of psychoacoustical results in the research on noise effects. In particular, we refer to spatial hearing and its possible implications for noise effects on man. Then, we will outline various results of preliminary experiments, concerning the influence of spatial hearing on the effects of road traffic noise and background speech on the serial recall of verbal material. These experiments were conducted with help of an artificial head system. They will also be demonstrated during the poster session of this conference, and will be described there in all the experimental and technical detail (Kilcher & Hellbrück, in this volume). The results of our so far conducted experiments, suggest that changes in the auditory space do not influence the performance in a serial recall task. However, binaural hearing may aid the detection of sound features which are expected to disrupt the phonological short-term store.

Noise Research and Psychoacoustics

Recently, Smith & Jones (1992) have presented a review about research on noise effects on human performance. They concluded that noise effects mainly depend on the nature of noise and tasks. Additional conditions, such as motivation, individual differences and contextual non-acoustical stressors may modify these effects.

The former noise research was restricted more or less to artificially created broadband noise, namely white or pink noise, and only one property of noise was varied, namely sound pressure level. On the one hand, this manipulation could be easily achieved with the technical means of that time. On the other hand, the existing noise in factories and other working places of those days may have suggested the hypothesis, that loudness could be the dominant acoustical factor inducing deteriorating effects on human behavior and performance. Noise was more or less equated to loudness. Spectro-temporal characteristics of sound were rather neglected. Today, however, by regulations of occupational safety administrations working places are protected against extremely loud noise, which could harm the ears. Furthermore, occupational work is shifting from hard physical work in noisy environments to mental work in rather quiet surroundings.

Thus, recent noise research calls to mind, that noise effects not only depend on the intensity of noise, but also on spectro-temporal characteristics of noise. Moreover, the interest in the nature of noise coincides with more intensive psychoacoustical research on spectral and temporal components of sound. Complex acoustical sensory magnitudes are investigated. Sensory pleasantness, for example, is found to be determined by sharpness (mainly depending on the spectral envelope of sound), roughness (depending on amplitude modulation) and tonality of sound (tone or noise quality of sound), all of them being well-defined psychoacustical magnitudes. Together with loudness they strongly influence noisiness (Zwicker & Fastl, 1990, p. 221). Timbre and rhythm are being more and more

psychoacoustically explored. Thereby, for the first time, the principles of gestalt psychology play an important role in acoustical research (Bregman, 1990). Knowledge concerning the perception of speech and music derives profit from such research. It is quite obvious that research on noise effect will also derive benefits from new psychoacoustics. Effects of irrelevant background speech and background music on phonological short-term store, one of the most stable effects of noise on performance (e.g. Jones & Morris, 1992; Klatte & Hellbrück, 1993; Salamé & Baddeley, 1982), was recently explained with regard to theories, such as Bregman's auditory stream theory (Jones, in press). The greater attention to such theories could mark a turning point in research on noise effects on performance. First, considering complex sounds of moderate intensity would be of greater ecological relevance. Second, the integration of psychoacoustics and cognitive research would put noise research on a broad basis.

An important domain of psychoacoustics is spatial hearing. Spatial hearing particularly concerns ecological perception. If we wish to extend the ecological validity of noise research we may not neglect the fact that man has two ears, which is not an extravagance of nature, but a necessity for spatial hearing, recognition and well-adapted behavior.

Spatial Hearing, Arousal and Cognition

What is spatial hearing, and what is the underlying process within the auditory system? The precondition of spatial hearing is binaural hearing. The localization of sound events outside of the head results from interaural comparisons. Outer ears filter sound depending on the direction, where sound comes from. By a lateral angle of sound incidence, the interaural time differences between the ears arise from the different distances between each ear and the sound source. Furthermore, interaural level differences result from deflections of sound waves caused by the head. However, such level differences strongly depend on the frequency of sound. Interaural comparisons occur on rather high levels of the central auditory system. In analyzing binaural signals the central auditory system shows an absolute amazing efficiency. It analyzes time gaps of μs-differences. Furthermore, the detectability of signals in noise is significantly enhanced by binaural hearing (cf. binaural masking level difference, BMLD). Listening to a certain speaker while attending a cocktail-party, one would have serious problems to understand speech if one ear would be blocked. Binaural hearing helps to enhance the signal-to-noise ratio and supports figure-ground separation.

From the view of evolutionary biology, signal detection, pattern recognition and localization of sound events are very important abilities, enabling us to control the environment. Hearing a sound informs us of an occuring event. If an object does not move or work, it is unlikely to make sound. Hearing is closely connected to movements and events in the environment. The ear is the sentinel of our senses. The auditory system is always on alert, thereby functioning as a warning system. Unlike the visual system, it is able to detect events even when they are hidden or behind us. For a vertebrate or a human being in prehistoric times, the exact localization of visually hidden events was a matter of life or death (as it might be for modern man in road traffic). The auditory system is closely tied to the perceptual system as a whole, as well as to the arousal system. By auditory reflexes head and eyes are oriented in the direction of sound, helping to identify the sound-producing objects. The arousal system supplies man with the necessary energy to react appropriately. Although many reactions to sound are culturally determined, adaptation to the environment has a biological basis and is supported by preattentive processes.

If we accept the thesis that binaural hearing is biologically essential to controlling the environment, as well as being important for signal detection, figure-ground separation and event perception, then the question arises, why in noise effect research binaural hearing has been taken so little into account. The reason may be that in many psychological laboratories the appropriate technology is not avåilable. Sound recordings using conventional monophonic techniques, however, suppress cues needed for spatial hearing. If in laboratory experiments the complex acoustic real-life situation should be simulated, artificial head

technique must be used. By artificial head technique together with digital storing (digital audio tapes, DAT) a virtual spatial hearing situation of high fidelity can be created. Furthermore, the reproduction of complex psychoacoustic properties, such as roughness, is remarkably improved through the use of such a technique (Genuit, 1991).

Is the effect of spatially heard noise different from the effect of monophonically recorded noise?

Recently, Notbohm et al. (1992) revealed in laboratory experiments, that industrial noise causes significantly stronger physiological reactions, then when it is recorded by an artificial head system. According to the authors' interpretation, these results are explained, roughly speaking, by the higher fidelity of artificial head techniques. It seems to be obvious, that embedding a person in a virtual spatial hearing situation may cause stronger psychophysiological responses. In a virtual spatial hearing situation, subjects are rather involved in the situation, and do not attend to an event in the same way as not concerned subjects. If, on the one hand, strong physiological effects are induced by noise presentations based on spatial hearing, why should, on the other hand, spatially heard noise not have any effects on mental performance? As far as we know, there exist no experiments concerning this question. Indeed, Colle (1980) and Jones et al. (1990) conducted experiments from which they concluded that in the case of irrelevant speech, different directions and movements of sound have no effects on mental tasks. In Colle's experiment a memory task was used. Jones et al. investigated the effects of irrelevant speech on proof reading. In these experiments, however, a localization of sound in the head rather than virtual spatial hearing was achieved by using a stereophonic technique. In the experiment carried out by Jones et al., three voices were presented either altogether in the central plane of the head or each voice in a seperate plane. Movements of a voice were achieved by changing the interaural level differences, thereby, inducing the impression of a voice moving within the head from one ear to the other. No effects could be shown for either the spatial location or for the moving. Thus, one may conclude, that selective attention and distraction can be ruled out as a deteriorating factor in mental task experiments using irrelevant background speech. The auditive event configuration, however, used in these experiments is not comparable to hearing events in the auditory space outside of the head. In real life we do not hear sensations but events.

Our concept of perception is a biological-functional one. Perception is regarded as an instrument which gives the base for controlled actions that are adapted to a certain environment (Prinz, 1983). Changes in the environment have to be registered in an early processing-stage if they significantly deviate from a schema of environment stored in memory. More than the other senses the auditory system functions as an automatic warning system working while attention is focussed on certain visual or mental tasks. Such tasks may be interrupted by preattentional processes induced by hints indicating relevant changes in the environment. Various sounds, such as impulse sounds indicate attention attracting events, usually without regard to the subject's activities. Other noise-induced disruptive effects on mental performance are determined by interference between sound and mental activities in which a person is currently involved.

Roughly speaking, we can expect general noise effects on the one hand, and specific noise effects on the other hand. With general noise effects we mean noise attracting full attention disregarding the subject's activities. Certain physical factors, such as intensity, tonality and modulation may distract a person. Warning signals, for example, have such specific features that effectively distract people's attention from their activities. But also sound indicating objects that are heading towards a person on a collision course are directly distractive.

On the other hand, specific noise effects refer to noise interfering with specific mental activities. For example, the irrelevant speech effect is such a specific effect, which occurs when immediate serial recall of visually presented verbal material is required, with simultaneous disruption through spoken material that the subject is instructed to ignore. The

disruptive effect seems to be independent of the meaning of the irrelevant material, with nonsense syllables or words in a foreign language being just as disruptive as meaningful material. Furthermore, performance is not disrupted by irrelevant white or pink noise, nor is loudness an important factor for either noise or speech. The irrelevant speech effect seems to be caused by an interference between speech, travelling from the ears to the central nervous system, and memorized verbal material which is tied to a serial order. Interfering running speech seems to loosen the knots between memorized items (Jones, in press).

Preliminary experimental results

As insinuated above, spatial hearing, noise and cognition include many aspects, that cannot be covered completely. Currently, we are just at the beginning of this research. Following the results of some preliminary experiments dealing with interactions mainly between irrelevant speech effect and spatial hearing conditions will be presented. All experiments reported below were conducted using a serial recall task. Nine digits were successively presented on a monitor. Subjects were instructed to write down the digits immediately after the sequence, in the order in which they had been presented. While performing the task, the subjects were presented with various kinds of background noise. The experiments are described in all methodical and technical detail by Kilcher & Hellbrück (in this volume).

Experiment 1

In connection to research on the irrelevant speech effect, there exists much evidence that unstructured artificial noise, such as white or pink noise, has no effect on the serial recall task, even if this noise is very loud. There is, however, little evidence concerning effects of every-day noise, such as industrial or traffic noise on the same task. As we know from the Notbohm et al. investigation (see above), such noise increases the arousal significantly if it is presented spatially. We created an auditory scene in which subjects were sitting in a room, facing a closed window and hearing road traffic noise, which was recorded with an artificial head system. The noise was presented over headphones. Thereby, it was possible to hear the passing traffic from the front. We compared this experimental condition with two other conditions. These conditions were chosen according to previous experiments (e.g. Klatte & Hellbrück, 1993). One of these was continuous Japanese background speech which has strong effects, whereas the white noise has no effects. All sounds were presented in moderate sound pressure levels (less than 70 dB). As figure 1 shows, spatially presented traffic noise has no effects.

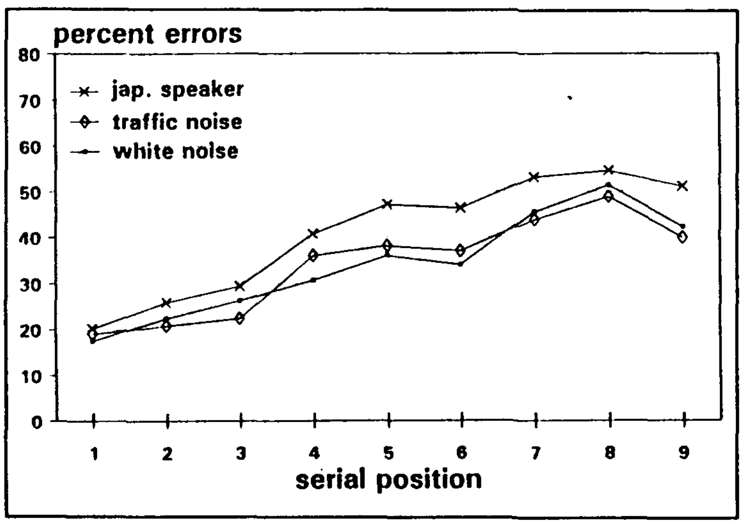

Fig. 1. Effects of spatially heard road traffic noise, monophonically recorded background speech and white noise on a serial recall task.

This may be interpreted as further evidence, that there is no effect on a serial recall task by arousal as well as distractions induced by permanent changes in the auditory space. Irrelevant speech effect seem to be a very specific noise effect, which is perhaps only sensitive to speechlike sound. What, however, makes a sound speechlike, and, moreover, does spatial hearing strengthen the effects of background speech?

Experiment 2

The interpretation of the irrelevant speech effect is not unequivocal. The most recent hypothesis is the 'auditory changing state'-hypothesis suggested by Jones (in press). According to his theory, an auditory stream capable of corrupting the phonological short-term memory, must show a certain degree of temporal-spectral change. This hypothesis is indirectly supported by experiments reported by Klatte & Hellbrück (1993). According to these experiments, background music based on glissando-tone sequences showed significantly less detrimental effects than music based on staccato-tone sequences. Just the same, babble noise did not seem to impair the task as much as a single speaker did, yet more than under the quiet condition. As figure 2 shows, a replication of the babble experiment verified the effect of the babble (Kilcher & Hellbrück, this volume).

How can we explain these gradual effects of irrelevant background speech? Superimposition of voices as in the babble makes the auditory stream smoother and more noise-like compared to the stream of a single voice. This interpretation is in line with the changing state-hypothesis.

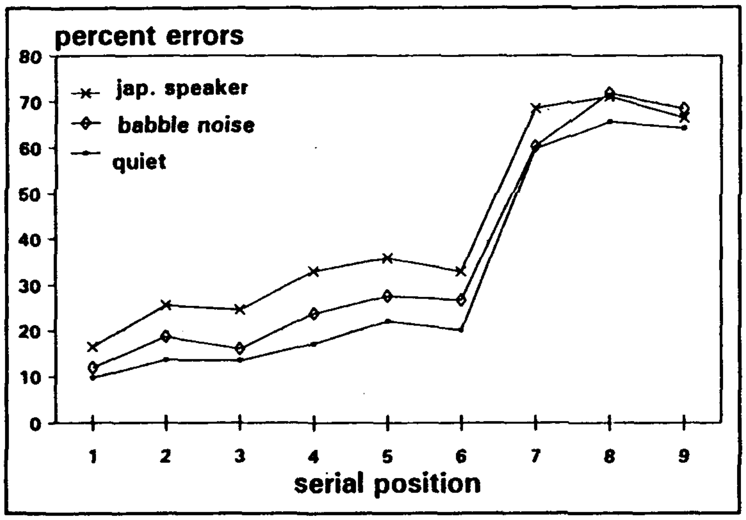

Fig. 2. Effects of babble noise (about 100 Japanese speakers) and single speech (Japanese) on the serial recall task.

Our next experiment was concerned with the question, whether or not spatial hearing enhances the effect of a babble. We created two auditory scenes, one consisting of two speakers, and the other one of eight speakers. Each of the scenes was recorded with the artificial head as well as with a conventional monophonic technique utilizing one microphone. The localization and separation of single speech streams within such a complex auditory scenes is easier with spatial hearing. Therefore, the auditory scene appears as complex and diverse as it actually is, when recorded with the artificial head system. With the monophonic technique, however, spatially separated streams merge into one auditory stream. One would, therefore, expect, the richer and more structured spatial hearing condition to cause stronger effects than the monophonic condition. The experiment, however, did not verify this hypothesis. The two-speakers stream and the eight-speakers stream differ with regard to superimposition of voices only. In other words, they differ with regard to the clarity of speech. As shown in figure 3, the two- and eight-speakers conditions

clearly reveal a different deterioration, disregarding the type of recording. The eight-speakers condition showed a diminished irrelevant speech effect. This finding coincides with the previous interpretation of the babble effect. From this finding as well as the findings reported above, one can conclude, that the irrelevant speech effect is gradual, and, moreover, the graduation does not depend on spatially changing state. Therefore, spatially determined acoustic diversity can be excluded as an interference factor. Assuming that the irrelevant speech effect depends only on clarity of speech, as suggested above, we should expect different effects between spatially and monophonically heard speech, which is presented in a partially masking noise. Binaural hearing improves intellegibility of speech in background noise (Binaural Intellegibility Level Difference, BILD).

Experiment 3

In the 3rd experiment, we created auditory scenes with background speech coming from different distances. As in experiment 1, we used Japanese spoken by a single speaker. Under one experimental condition the background speech was right behind the subject's back, whereas under the other condition, the background speech came from a distant source. In both cases, traffic noise was virtually entering from a window located at a medium distance. Of course, the speech coming from the distant source is softer than that of a nearby source, even though the intensity is the same in both cases. According to previous experiments, however, loudness should not affect the irrelevant speech effect (see above). Furthermore, the distant speech is partially masked by traffic. Nevertheless, the speech was clearly audible, if one attended to the speech.

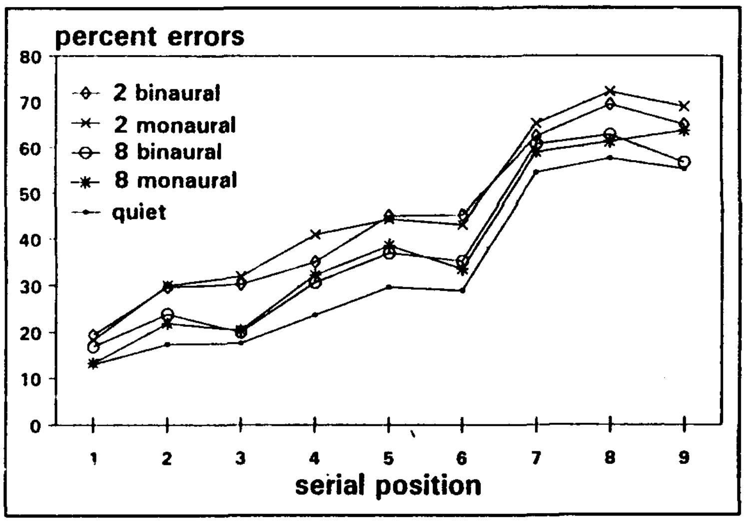

Fig. 3. Effects of two and eight superimposed voices, respectively. Each of the two acoustic conditions were recorded 1) monophonically and 2) with an artificial head (binaural) on the other hand.

Both auditory situations were recorded monophonically as well as with the artificial head. With the artificial head recording, the hearing system is able to analyze the auditory scene binaurally. Thereby, speech can be separated better from noise, and the distance of speaking source becomes evident. Under the condition, where the speaker is close behind the back of the subjects, they reported after the experiment, that they felt beset by the speaker and were hardly able to ignore him. When the source was more distant, however, it was easy for them to ignore the speech. Thus, we expected clear irrelevant speech effects with the nearby source, and were doubtful of effects of distant speech. If the irrelevant speech effect is not a matter of loudness, then the far-distant speech should approximately achieve the same effect. If, however, the effect depends on clarity of speech, as assumed above, we should expect a reduced irrelevant speech effect in the case of a distant source. With artificial head recording, however, clarity of speech is higher. Therefore, in any case

one can expect a stronger irrelevant speech effect. In other words, we expect two main effects, one of distance, and the other one of recording type.

Two independent preliminary experiments were carried out, one with monophonic presentation, and the other one with artificial head presentation. Unfortunately, we could not complete the experiments as yet. The preliminary results are shown in figure 4. As one can see, the results show a clear effect of the nearby-condition, while under the far-distant condition a weaker effect resulted. At a glance, the spatially heard scene seems to differ from the monophonic scene. Due to the preliminary status of the experiments, however, one must be careful not to interpret the results as statistically proven. Nevertheless, one may draw conclusions from experiment 3 in two respects. First, in addition to the results of experiment 2, there seems to be additional evidence, that the irrelevant speech effect is gradual. Irrelevant speech is not a matter of all-or-none. Also in the 3rd experiment, this could be due to speech clarity. Clarity of speech is reduced if the speech stream comes from a far-distant source through a 'wall' of masking noise. Second, in masking noise spatial hearing possibly enhances the irrelevant speech effect, perhaps by improving the signal-to-noise ratio.

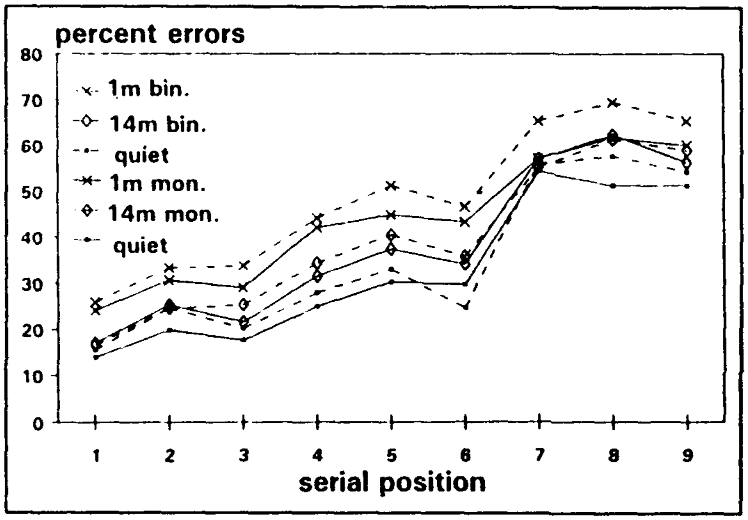

Fig. 4. Effects of irrelevant speech heard from varying distances, monophonically (mon) recorded and with artificial head (bin), respectively.

Conclusions

Does binaural hearing influence the noise effects on mental performance? We have mainly carried out experiments concerned with the irrelevant speech effect. From the sofar conducted experiments one can conclude that the irrelevant speech effect is a very specific noise effect. It is limited to tasks demanding short-term retention of verbal material, and it seems to depend exclusively on temporal changes of the auditory stream going through the auditory system. Diversity of auditory space does not seem to affect the irrelevant speech effect, at least, when verbal material must be retained in sequential order. However, there seems to be some evidence that spatial hearing might influence the irrelevant speech effect by making speech more clearly audible.

So far, we do not know whether diversity and movements in the auditory space influence tasks based on the visuo-spatial scratch-pad, e.g. when visual material has to be localized or scanned in imagery. Neither do we know exactly which spatial features an auditory scene must have to cause obliged attentional distraction. Attentional distractions could be a matter of an auditory warning system. Such a system should be implemented in a slave system of the working memory, always on alert while the central executive is concerned with the actual work. (Hereby, we refer to the Baddeley-Hitch model of working memory; cf. Baddeley, 1986.) In order to protect the body from possible dangerous events, the warning

system must be in touch with the environment at all times. An appropriate warning must guaranteed by reliably registering significant deviations from an internal model of the environment. Such a model should be incorporated in an acoustically based subsystem of the working memory.

In conclusion, a few words concerning the future. Artificial head recordings are very impressive, and what is heard may be called virtual reality. Though we endeavoured to create a realistic auditory scene by performing the experiments in the same room and under the same conditions as the recordings were made, subjects were obviously aware of being in an artificial laboratory context. Nevertheless, we expect the artificial head technique to become widely used as an appropriate measure to enhance the so-called ecological validity of noise research, without forgoing strict experimental control.

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THE IRRELEVANT SPEECH EFFECT: IS BINAURAL PROCESSING RELEVANT OR IRRELEVANT?

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Abstract

A series of four experiments studied the effects of irrelevant speech on the immediate memory for visually presented digits. Various sounds were recorded simultaneously, by using an artificial head system (binaural condition), in addition to a monophonic microphone (monaural condition). The results indicate that disruption of memory in serial recall tasks depends mainly on sound features, other than cues contained in binaural recordings. By varying the distance of the speakers to the recording systems, as well as the number of speakers, the extent of disruption could be varied, thereby, indicating that the effect is not based on an "all-or-none"-principle, but rather varies gradually.

Introduction

The disruptive effect of irrelevant background speech on serial recall of visually presented items has been replicated frequently and is regarded as a stable effect.
There exists evidence that speech sounds disrupt performance, while various other sounds (e. g. white or pink noise) have no effect. Even more, speech sounds were shown to cause disruption to the same extent, regardless of the meaningfulness of the spoken material (native speech, foreign speech, reversed speech; see Jones, Miles and Page, 1990), or of the intensity (between 40 and 76 dB(A); see e. g. Colle, 1980).
On the other hand, several results point out that varying speech sounds cause different degrees of disruption. Klatte and Hellbrück (1993) demonstrated in an experiment, that a background "babble noise", comprised of approximately 100 speakers, caused significantly worse performance than a quiet condition, but led to significantly better performance than a single Japanese speaker.
In a series of experiments reported here we tried to find background sounds which can cause disruptive effects of different degrees.

Experiment 1

This was a replication of the experiment of Klatte and Hellbrück (1993) with respect to the Japanese speaker, babble noise and quiet condition.
Method: The digits 1 to 9 were presented successively in random order without repetition, on the monitor of a microcomputer for 750 msec. with an interval of 250 msec. between the digits. After nine digits, there was a pause of 13 seconds, allowing the subject to record the digits on the answer-sheet. After a visual warning of two seconds, the next sequence of nine digits was presented. The subjects were instructed to group the digits by threes, but not to read aloud, and write them down in the presented order, immediately after the last digit. They were instructed to recall any digits and to guess if they were not sure. Furthermore they were requested to ignore the background sound as much as possible.
Subjects: 24 (12 male and 12 female) psychology students with an average age of 23 participated.
Material: Digital tape recordings of a single Japanese speaker and a babble noise, comprised of approximately 100 Japanese students, were presented over a *DYNAUDIO* loudspeaker at an intensity of 61 dB(A), which was placed three meters behind the subjects. In the quiet condition the intensity level was 40 dB(A).
Design and Procedure: Subjects were tested individually in a repeated measures design, in which the order of the experimental conditions was balanced. Written instructions were given to the

subjects and repeated verbally by the experimenter. After nine practice trials which were not considered in the calculation, the subjects had to perform 27 experimental trials in each condition. These 27 trials were divided into three intervals ot nine trials each, divided respectively by a short ten second pause. Between each condition there was a three minute pause. The experiment itself lasted 50 minutes.

Results: A two factor repeated measures ANOVA showed significant main effects of conditions, $F(2;46)=20.22$, $p<0.01$, and of serial positions, $F(8;184)=59.61$, $p<0,01$. No interactions of condition by serial position resulted $F(16;368)=1.42$, $p>0.05$. A Newman-Keuls test indicated that the quiet condition was significantly better than the babble noise ($p<0.05$), which in turn was significantly better than the Japanese speaker ($p<0.01$).

Figure 1 shows the performance of subjects across the three conditions. In the lower part of Figure 1, the waveforms of a 10 second sound interval are presented, first the Japanese speaker, and then the babble noise.

Experiment 2

Method: Same as Experiment 1, with the exception, that the digits were presented for 500 msec.

Subjects: 18 (10 male and 8 female) psychology students with an average age of 22 participated. None of them took part in the previous experiment.

Material: The same tape recording of the Japanese speaker was used. In addition, we made digital tape recordings of white noise and traffic noise with an artificial head system HRS II.2 by *HEAD ACOUSTICS*. Sounds were presented over *BEYERDYNAMIC DT 770* headphones at an intensity of approximately 50 dB(A).

Design and Procedure: Same as Experiment 1.

Results: An ANOVA for repeated measures showed significant main effects of conditions $F(2;34)=3.65$, $p<0.05$ and serial positions $F(8;136)=9.61$, $p<0.01$, with no interaction between the two factors $F(16;272)=1.16$, $p>0.05$. A Newman-Keuls test indicated that the Japanese speaker condition was significantly worse than the two other conditions ($p<0.05$). Binaurally recorded traffic noise and white noise showed no significant differences ($p>0.05$). The performance across the three conditions is shown in the upper part of Figure 2. Below the graph, the waveforms for a 10 second interval of the traffic noise and white noise, respectively, are shown.

Experiment 3

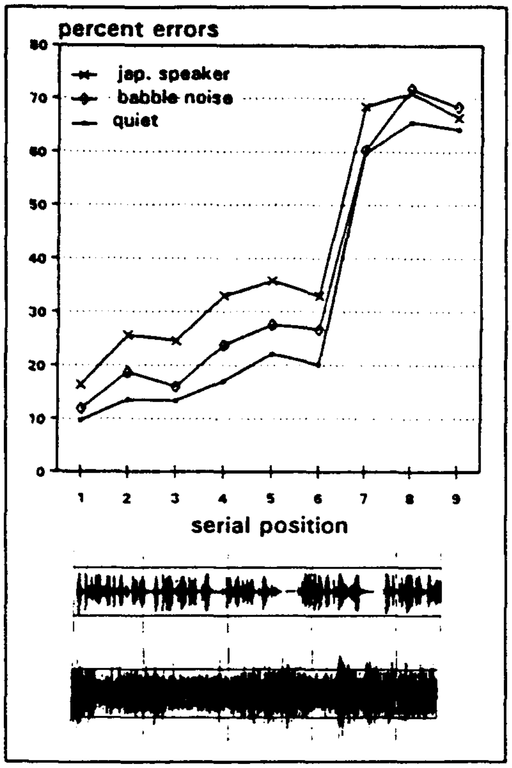
Method: Same as Experiment 1.

Subjects: 30 (14 male and 16 female) psychology students with an average age of 23 participated. None of them took part in the previous experiments.

Material: Two speakers and eight speakers, respectively, were recorded simultaneously by two different recording systems: with the artificial head system described above and with a monophonic microphone Type *MB C 91540*. In the (binaural and monaural) two speaker conditions, two female speakers read an english and a spanish text, standing at a distance of eight meters on the left and right side of the recording units. In the eight speaker conditions, eight female students moved around behind the recording units in an area of about 12 by 12 meters, with the restriction not to approach the microphones closer than three meters. They were talking to each other in German. The sounds were presented by the headphones used in Experiment 2 at an intensity of 51 to 55 dB(A).

Design and Procedure: Mainly as in Experiment 1. The presentation order of the five conditions (two/eight speakers, binaurally/monaurally recorded, quiet) was balanced by two 5x5 Latin Squares. Due to the increased number of conditions, each condition comprised only 18 trials. The experiment lasted 70 minutes.

Results: An ANOVA showed significant main effects of conditions $F(4;116)=18.09$, $p<0.01$ and serial positions $F(8;232)=83.14$, $p<0.01$, but no significant condition by position interaction $F(32;928)=1.32$, $p>0.05$. A Newman-Keuls test indicated no significant differences, neither between the two speakers bin. and the two speakers mon. condition ($p>0.05$), nor between the eight speakers bin. and eight speakers mon. condition ($p>0.05$). Both eight speaker conditions were significantly better than both two speaker conditions ($p<0.01$) and significantly worse than the quiet condition ($p<0.01$). Figure 3 shows the performance across the five conditions. The waveforms (10 second intervals) of the monaural conditions (two speakers above, eight



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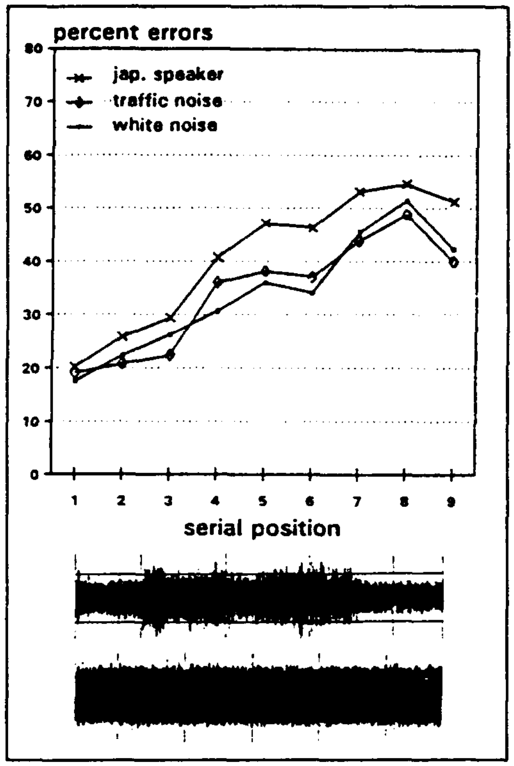

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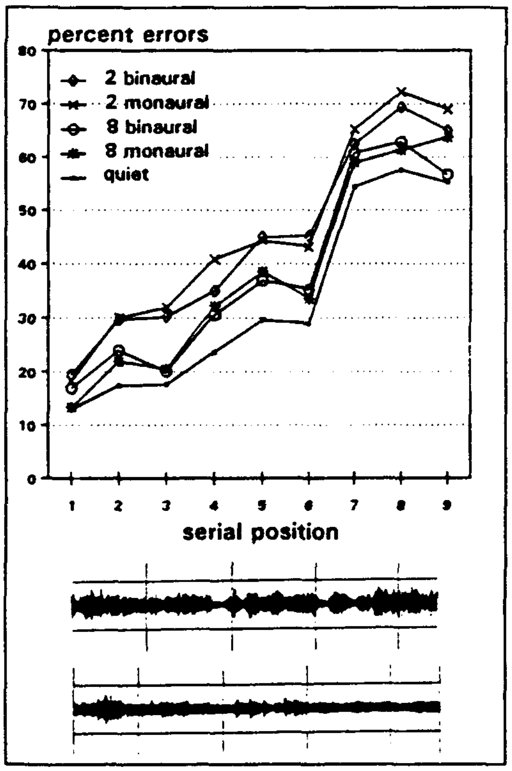

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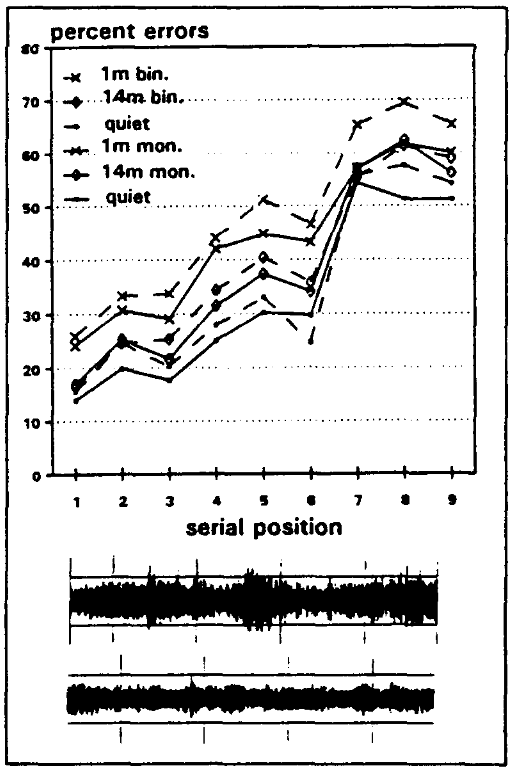

Figure 4.

speakers below) are shown in the lower part of Figure 3. They do not differ from the binaural conditions.

Experiment 4

Experiment 4 is a preliminary test of the influence of distance of the speaker on the performance of the subject. Due to the restricted number of subjects, no statistical analysis was performed.
Method: The conditions were varied between-subjects with respect to monaural/binaural recordings and within-subjects with respect to distance.
Subjects: A total of 24 (8 male and 16 female) psychology students with an average age of 24 partitcipated.
Material: In order to maintain equivalent verbal conditions, new recordings were made by presenting the Japanese speaker of the previous experiments over a loudspeaker at a distance of 1 meter and 14 meters, respectively, behind the recording units. In addition the traffic noise of Experiment 2 was presented over a loudspeaker at a distance of 8 meters on the left side behind the recording units. Recordings were made binaurally and monaurally simultaneously. The intensity of all sounds were held constant in the 1 meter and 14 meter conditions. The sounds were presented at an intensity of 51 dB(A) in the 14 meter conditions and at 57 dB(A) in the 1 meter conditions over the headphones used in the previous experiments.
Design and Procedure: The subjects were first randomly assigned to the monaural or binaural treatment and then received the 1 meter, 14 meters and quiet conditions in a balanced order. The experiment was carried out in the same room, in which the recordings were made in order to have the acoustical as well as the visual impression of distance.
Results: Figure 4 shows the performance of both treatments across the conditions. Again, in the lower part the waveforms of the (monaural) 1 meter and 14 meter condition are shown.

General Discussion

In our first experiment we successfully replicated the results of Klatte and Hellbrück (1993), thereby, indicating that different sounds lead to disruptive effects in different degrees, rather than being an all-or-none effect. Our purpose was to find background sounds that cause disruptive effects of different intensity. We achieved this, by varying several features. First, we recorded sounds with an artificial head system and were thus able to present conditions in artificial situations (such as experiments), that are more likely to represent real world situations (at least with respect to the quality of the heard material). For a further discussion of this point, see Hellbrück and Kilcher (in this volume). Second, we could demonstrate, that effects occur in different degrees, even when the number of speakers is varied from two to eight (rather than from 1 to 100 speakers). The same effect seems to occur, when the distance between a speaker and the subject is varied.
What happens to the sounds, when the number of speakers or the distance is increased? Hearing several voices at the same time, makes it more difficult to distinguish single speech streams. Hearing a voice from a distant source, sounds differently than a recording just reduced in volume. The "changing state hypothesis", provided by Jones (in press), emphasizes specific features of sound, rather than simply distinguishing between speech and non-speech as the responsible characteristics for the irrelevant speech effect.

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SUMMARY OF TEAM 4
EFFECTS OF NOISE ON PERFORMANCE AND BEHAVIOUR

09th July 1993

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Following the last Stockholm's Congress, the major directions for future research that have been outlined by our past late chairman, Dr Donald Broadbent, comprised mainly the need to initiate some field and longitudinal studies concerned with the effects of chronic exposure to noise on performance, and to pursue the work into the new area of the irrelevant speech effect. These lines of research as well as other related areas have been explored in details during the last five years. This summary will therefore comprise a) a brief review of what has been done since 1988 and presented by members of Team 4 during this Congress, and b) an outline of some directions for future research.

In the plenary session, we heard a report that described the first wave of a longitudinal study concerned with the effects of chronic exposition to airport noises - the Munich Airport - on physiological variables and on psychological performances in children. Children exposed to chronic aircraft noise have elevated adrenaline and nor-adrenaline levels. Clear impairments of performance in some tasks have been pointed out, but not in others. In auditory, perceptual tasks, there seems to be a general adaptation to noise. In non-reading tasks, no reliable effects were obtained, but tasks that rely on memory and on reading (long-term recall) showed impairments of performance with chronic noise exposure.

We heard also two substancial analyses of the irrelevant speech effect, acting as a background noise, on cognitive performance. In short term memory tasks, it has mainly been shown that the irrelevant speech effect is not peripheral and does not relate to distraction. Monaural or binaural speech sounds presented simultaneously with the visual material to be recalled led to comparable impairments of performance. Rather, it reflects serious impairments of the information processing at the memory stage. Being central, the effect does, however, depend crucially on the type of task. Short-term memory tasks are not sensitive to the meaning of the oral speech, but proofreading tasks seem to be sensitive to meaning. The interaction of the auditory speech with different kinds of cognitive tasks should be systematically explored.

The oral communications covered several issues and pointed to both negative and positive effects of noise. One paper examined the potential rôle of effort and its interaction with the detrimental effects of noise. Because the issue related to the psychological cost of exposure to noise might have important practical implications, the concept of effort would need some specific laboratory investigations at a methodological level to find out the suitable parameter(s) that would quantify effort at best. It has also been shown that loud noise would reduce the psychosocial behaviour of tolerance, and would increase frustration. Other studies have also pointed to some indirect **beneficial** effects of noise a) in increasing temporarily the level of vigilance in car driving, and 2) in wiping out the detrimental effects of sleep inertia on some cognitive performance. Finally, it should perhaps be mentioned that 4 oral communications out of 12 that were listed in the preliminary programme of the Congress have not been given at all, and this is regrettable.

Directions for future research

In his 1988's Summary of Team 4, Donald Broadbent claimed:

> "...it is both traditional and desirable that teams should interact rather than remaining exclusively separate."

A clear emphasis is made by members of Team 4 on the necessity of making **field** and **inter-team** studies, in line with this claim.

a) Much work should be devoted to the effects of different kinds of noise on performance in **children**. The results already obtained in the longitudinal study in children that are chronically exposed to airport noise should be expanded. Because of control difficulties that are inherent to field research, there is a need to compare the field results with those obtained in laboratory experiments.

b) Field studies are necessary to explore the relationships between noise exposure and the occurence of accidents.

c) Future studies should focuse on the exploration of the rôle of irrelevant speech on **office** tasks other than those that imply short-term recall only. The aim is to assess the validity of the irrelevant speech effect on a wider range of cognitive tasks such as mental arithmetic, comprehension, proofreading, and retrieval from long-term memory.

d) It becomes important to understand the mechanisms underlying the various effects of noise on performance. On both ecological and theoretical grounds, one should try to answer the central questions of what does make speech as speech, and why does speech have deleterious effects upon some cognitive performance.

e) Due to the robustness of the irrelevant speech effect, there is a need to explore the way of developing methods of abatement to irrelevant speech in offices.

f) The individual differences in the effects of noise on performance should be taken into account. The psychophysiological approaches are promising and should be better explored, to understand the neurotransmitter basis of noise effects (nor-adrenaline), and to examine the relationships between noise and illness on subsequent performance.

Résumé de la session 4

Effets du bruit sur les performances et le comportement

9 juillet 1993

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Suite au dernier congrès de Stockholm, les principales directions pour la recherche future qui ont été exposées par notre précédent président, Dr Donald Broadbent, englobaient principalement le besoin de promouvoir quelques études longitudinales sur le terrain en rapport avec les effets de l'exposition chronique au bruit sur la performance, et de poursuivre le travail dans le nouveau domaine de l'effet de non pertinence du discours. Ces lignes de recherche ainsi que d'autres domaines qui s'y rattachent ont été étudiées en détail durant les cinq dernières années. Ce résumé comprendra donc : a) un bref examen de ce qui a été fait depuis 1988 et présenté durant ce congrès par les membres de la session 4 et b) une esquisse de quelques directions pour la recherche future.

Dans la session plénière, nous avons assisté à un rapport qui décrivait la première vague d'étude longitudinale traitant des effets d'exposition chronique aux bruits d'aéroport - l'aéroport de Munich - sur les variables physiologiques et sur les performances psychologiques des enfants. Les enfants exposés au bruit chronique d'aéroport ont des niveaux d'adrénaline élevés. Des baisses évidentes de performance ont été signalées dans quelques tâches, mais pas dans les autres. Dans les tâches auditives et perceptives, il semble y avoir une adaptation générale au bruit. Dans les tâches sans lecture, les effets observés ne sont pas fiables, mais les tâches qui ont rapport à la mémoire et la lecture (souvenir à long terme) on montré des baisses de performance avec l'exposition chronique au bruit.

Nous avons aussi écouté deux analyses importantes sur l'effet de la non pertinence du discours, agissant comme un bruit de fond, sur la performance cognitive. Dans les tâches mentales de courte durée, il a essentiellement été montré que l'effet de la non pertinence du discours n'est pas périphérique et n'a pas de rapport avec la distraction. Des bruits de conversation monophonique et binaurale présentés en même temps que le matériel visuel à mémoriser ont menés à des baisses de performance comparables. Plus exactement, ils démontrent de sérieuses diminutions du traitement de l'information au stade de la mémoire. Étant central, l'effet dépend toutefois de façon décisive du type de tâche. Les tâches de mémorisation à court terme ne sont pas sensibles à la signification de l'élocution orale, mais les tâches de correction des épreuves semblent être sensibles au sens. L'interaction du discours auditif avec différentes sortes de tâches cognitives devraient être étudiée de façon systématique.

Les communications orales ont recouvert plusieurs questions et ont montré les effets positifs et négatifs du bruit. Un papier a examiné le rôle potentiel de l'effort et son interaction avec les effets nuisibles du bruit. Parce-que la question liée au coût psychologique de l'exposition au bruit pourrait avoir d'importantes implications pratiques, le concept d'effort aurait besoin de quelques enquêtes spécifiques en laboratoire au niveau méthodologique pour trouver le(s) paramètre(s) qui pourraient quantifier au mieux l'effort. Il a également été démontré qu'un fort bruit pourrait réduire le comportement psychosocial de la tolérance, et pourrait augmenter la frustration. D'autres études ont également indiqué quelques effets bénéfiques indirects du bruit a) en augmentant très temporairement le niveau de vigilance de la conduite automobile avant une diminution sensible, et 2) en effaçant les effets nuisibles de l'inertie du sommeil sur certaines performances cognitives.

Directions pour la recherche future :

Dans son résumé de 1988, Donald Broadbent déclarait :

"... c'est à la fois une tradition et un désir que les équipes puissent échanger plutôt que rester exclusivement séparées"

Un net accent est mis par les membres de la session 4 sur la nécessité de faire des études sur le terrain qui soient inter-sessions, conformément à cette déclaration.

a) Beaucoup de travail devrait être effectué sur les effets des différentes sources de bruit sur la performance des enfants. Les résultats déjà obtenus dans l'étude longitudinale des enfants qui sont exposés

chroniquement au bruit d'aéroport devraient augmenter. A cause des difficultés de contrôle qui sont propres à ce domaine de recherche, il est nécessaire de comparer les résultats sur le terrain avec ceux obtenus dans les expérimentations de laboratoire.

b) Les études sur le terrain sont nécessaires pour étudier les relations entre l'exposition au bruit et l'apparition d'accidents.

c) Les études futures devraient se concentrer sur la découverte du rôle de la non pertinence du discours sur les tâches de bureau autres que celles qui impliquent seulement la mémoire à court terme. Le but est d'évaluer la validité de l'effet de non pertinence du discours sur une gamme plus large de tâches cognitives telles que le calcul mental, la compréhension, la correction des épreuves, et la récupération de la mémoire à long terme.

d) Il devient important de comprendre les mécanismes soulignant les divers effets du bruit sur la performance. Pour des raisons écologiques et théoriques, on devrait essayer de répondre aux questions centrales de ce qui fait du discours un discours, et pourquoi le discours a des effets nuisibles sur certaines performances cognitives.

e) A cause de la solidité de l'effet de non pertinence du discours, il est nécessaire d'étudier la façon de développer les méthodes de diminution de la non pertinence du discours dans les bureaux.

f) Les différences individuelles dans les effets du bruit sur la performance devraient être prises en compte. Les approches psychophysiologiques sont prometteuses et devraient être mieux utilisées, pour comprendre la base neuro-émettrice des effets du bruit (adrénaline normale), et pour examiner les relations entre bruit et maladie sur la performance ultérieure.

RESEARCH ON NOISE AND SLEEP SINCE 1988: PRESENT STATE

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Sleep disturbances are generally considered as the most serious effect from noise exposure in our living areas. Several countries have thus adopted noise indices with a penalty for nightly occuring noise, or stronger guidelines for noise limits during night.
Since 1988, about twenty new studies have been published in international journals or conference books in this research area. Most of these publications dealt with one or more of the specific topics, that were considered as the most important by the last ICBEN Congresses.

The main topics are:
- *predictive indicators of sleep disturbances for presumed health effects*
- *critical groups with a particular sensitivity to noise*
- *most sensitive period of the night*
- *significant components of noise and upper noise limits*
- *long term effects of countermeasures*

Predictive indicators of sleep disturbances for presumed health effects.

Effects of noise on time for falling asleep

This effect is considered as an important aspect of noise-induced sleep disturbance by the exposed individual. To overcome noise-induced stress some people may have chosen to move to a more quiet bedroom, others may keep their windows shut, use earplugs or sleeping pills or, if possible, move to a more quiet living area.
In most studies time for falling asleep is measured by latency to sleep stage 2 (EEG) (1,2,3,4,5,6), by questionnaires (7,8,9,10) or by observation (11,12). Eberhardt (5) found that children needed 7 minutes less to fall asleep when the noise level in their homes was reduced by 11 dBA, which is about the same as Griefahn and Gros (1) found among adults in their field study. In a laboratory study, Terzano *et al* (6) found an increase in sleep latency by 16 minutes among subjects exposed to recorded, continuous, white noise of 65 dBA, as compared to quiet conditions, whereas a slight *decrease* was found at 45 dBA. Other laboratory studies (8, 22 and Öhrström this conference), have shown a significant increase in subjectively estimated time for falling asleep (14 - 22 minutes) among subjects exposed to different numbers of single noise

events of 45, 50 and 60 dBA from recorded truck noise.
Kozarny (11) observed the afternoon sleep of 2.505 children in nursery schools. In schools with outside noise levels above 65 dBA Leq, the children had a prolonged time of falling asleep as well as difficulties falling asleep again after awakenings.
In two studies, different types of continuous noise were used to *induce* sleep. Spencer *et al* (12) used 5 minutes of white noise at 67 dB to faciliate sleep onset among newborn babies. They found, by observation, that sleep latency was reduced as compared to a control group. Topf (4) conducted a laboratory experiment in a hospital, involving 105 subjects divided into three groups (quiet, recorded hospital noise Leq 56.3 and noise + personal control by using (or not) a masking noise at a level of their own choice). She found that the "personal control group" had about 6 minutes shorter latency to stage 2 as compared to the noise group, though other sleep parameters were more negatively affected by the masking noise.

- A general finding is thus that noise increases the time for falling asleep (objectively as well as subjectively measured) of about 5 - 20 minutes. This effect occurs at low maximum noise levels from intermittent noise of 45 dBA, and the difference between background and maximum noise level seems to be of more importance than the absolute noise level (5,8). Continuous and even noise might in some circumstances faciliate sleep onset (4,6,12).

Effects during the sleep period
Primary effects are changes in EEG-activity such as transient alterations within a sleep stage, sleep stage shifts, alterations of the amount and the distribution of the different sleep stages and awakenings (also measured by questionnaire or behavioral awakening). Other physiological reactions are cardiac responses, constriction of peripheral vessels and body movements.
Results from the four European country study (13), convincingly showed a consistant effect of noise on *cardiovascular response*. Vallet (14) found that cardiac reactions commence at road traffic of 32 dBA as measured within the bedrooms. Di Nisi *et al* (15) reported a significant increase in *heart rate response* and *finger pulse amplitude* to single events from airplane, truck, train and motorbike noise of 56 - 71 dBA. These cardio-vascular reactions were greater during sleep than during awake.

Concerning *EEG-effects*, it is generally assumed that continuous noise has a more pronounced effect on REM sleep whereas intermittent noise causes a decrease in deep sleep stage 3 and 4, and shifts to lighter sleep stages or wakefulness (17). However, EEG-effects have sometimes been difficult to interpret (13,18). Thiessen (18) discussed problems concerning the definition of sleep cycles and stressed the importance of the great individual differences for the interpretation of the results in terms of mean response reactions.
An interesting finding is reported concerning the *transient EEG alterations* during sleep, referred

to as CAP - cyclic alterating pattern by Terzano *et al* (6) or TAP - transient activating phases by Di Nisi *et al* (15) and Bach *et al* (16). These changes are under the control of the reticular formation and are, like those of the cardiovascular system, directly related to the reticular arousal induced by heat and noise (16). These microstructural changes are very sensitive to noise and show a linear increase with the noise level (6). Moreover, a significant relationship was found between the frequency of these reactions and subjective sleep quality (6) as well as noise-sensitivity (15).

Awakenings from noise occur from about 50 dBA, depending on sensitivity and sleep stage. As opposed to cardiac and transient arousal reactions, habituation often takes place after some time. Saletu *et al* (19) observed increased intermittent awakening among subjects exposed to traffic noise with an Leq-level of 75,6 dBA.

Body movements could be seen as a rough measure of the sleep pattern. They are related to sleep stage shifts and awakenings. Large inter-individual differences exist in number of body movements during sleep (8). During noise-disturbed sleep, the total number of body movements is usually unaffected (8), or the increase is very small (5). An increased number of body movements (independent of noise level) has, however, been found as an arousal reaction induced by single noise events from trucks at 50 and 60 dBA (8). Kozarny (11) observed a significant increase in number of body movements as well as increased number of awakening episodes and a shortening of sleep time among children in nursery schools with outside noise levels above 65 dBA Leq.

- At the present time, cardiac reactions and transient EEG-alterations are probably the most sensitive indicators of noise-induced sleep disturbances *during* the sleep period.

After effects

These effects are observed during awake. They are assessment of subjective sleep quality - which takes into account difficulties to fall asleep, awakenings as well as feelings in the morning (7,8). Other after-effects are effects on mood, tiredness during morning and day as well as performance effects and long term effects on psycho-social wellbeing.

Subjective sleep quality was considered as an important indicator of noise-disturbed sleep in the four country CEC-study (13). The common results showed a significant decrease in sleep quality with 7% and a prolonged reaction time on a simple reaction-time test as compared to more quiet conditions. In another field survey with an Leq-level of 72 dBA (9), sleep quality was found to decrease, and tiredness during day time was higher as compared to a quiet control area. In a more recent field survey (21 - Öhrström this conference) in six different areas with Leq-levels

between 61 and 74 dBA, a lower sleep quality was found among those having bedroom windows at the most exposed side of the house.
Laboratory experiments have shown a somewhat larger effect of nois-. Among subjects with moderate sensitivity to noise, a decrease in sleep quality of 26 % was found at 50 dBA, and 39 % at 60 dBA from 64 recorded truck noises (8).

Subjective sleep quality has not always been found to be very closely related to physiological measures: However Topf (4) found a significant relation between seven out of nineteen physiological measures and Terzano (6) reported a significant relation between transient alteration of the EEG-pattern and subjective sleep quality.

Decreased *psycho-social wellbeing* (9,10) and a higher frequency of *symptoms like headaches, nervous stomach and decreased social orientation* has been reported (9) in areas with Leq-levels of about 72 dBA as compared to quiet control areas. In another field study (21) in six different areas with Leq-levels between 61 and 74 dBA, no difference in psycho-social wellbeing was found as compared to a quiet control area. In the noisy areas, however, a lower psycho-social wellbeing was found among those having bedroom windows facing the street.

- These studies suggest that people who are exposed to noise during day and night for several years, suffer from long term after effects and psychological health effects.

Critical groups with a particular sensitivity to noise

Shiftworkers, and especially older persons, are generally expected to be more sensitive to noise during sleep due to altered daily rythm and the usually higher noise level during day-time sleep. Nicolas (3) reported an increase of slow-wave sleep during daytime sleep and an decrease of Stage 2 and REM sleep latencies which was reflected in a better subjectively estimated sleep quality of daytime sleep. No differences were found in cardiovascular reactions during day and night sleep. The unexpected results might be due to the relatively young age of the shiftworkes (35 SD 5 years of age).

Noise sensitivity, as estimated by the individual, has been found to increase the risk for sleep disturbances in terms of decreaed subjective sleep quality (22). Di Nisi (15) found a higher heart rate reaction to daytime noise in noise-sensitive subjects but this difference could not be found for finger pulse response. When the same subjects were exposed to noise during night-sleep, no difference according to cardiac responses were found between the groups. However, a significantly higher frequency of transient activation phases was present in the high-sensitivity

group but not in the low-sensitivity group.

- At the present, it seems thus unclear whether noise-sensitive subjects are more vulnarable to physiological reactions during sleep, whereas earlier studies (22) clearly show a more pronounced effect on subjective sleep quality among noise sensitive subjects.

If *individuals with a high day-time noise load* should be considered as a vulnerable group is not clear. Fruhstorfer (23) concludes in her study that "Altogether, it has been shown that strong auditory input during the day provokes after-effects on subsequent night sleep pattern." She found a significant reduction in REM sleep, shortened sleep cycles and an increase in slow wave sleep during the second sleep cycle. She interprets these disturbances of the sleep processes as an intensified need for recovery after high day-time exposure to 85 dBA industrial noise. But "it remains unclear whether the sensory load itself or a secondary emotional load was the underlying cause of the observed REM sleep effects."

Concerning the effects of noise on the sleep of *ill people*, who are also considered as a vulnarable group, no data are avaliable in the literature.

Most sensitive period of the night

Griefahn (24) exposed two groups uf subjects to prerecorded shots of tanks (78-82 dBA) during three hours after lights out or in the early morning. The early morning group had a stronger heart rate response than the group exposed during the first hours of the night.

- Since sleep during early morning is lighter, this finding is expected. It should be noted however, that several studies show that noise during the evening and early night lead to an increase in time to fall asleep and a decreased sleep quality.

Significant components of noise and upper limits

Intermittent noise generally causes greater sleep disturbances than continuous noise, which stresses the importance of single high level noise events. It is, however, still not clear when an intermittent noise starts to be experienced as continuous.
The results by Di Nisi *et al* (15) and Bach *et al* (16) show that sleep disturbance reactions are different for different kinds of noises. The results are contradictory. While Bach *et al* found that the nature of the cardiovascular response was dependent on the type of noise - motorbike noise

led to greater reactions than truck noise with a higher noise level, Di Nisi *et al* found that sleep disturbances were related to the Leq-level from airplane, truck, train and motorbike noises. However. since the possibility to perceive the noise is important for the reaction, the background noise (pink noise versus road traffic noise) may to some extent explain these different findings.

Noise accompanied by vibrations (which occur in situations with heavy vehicles like trucks or trains in areas with clay) have been shown to increase sleep disturbances (25).

The choise of *upper limits* for noise depends upon the type of noise source as well as the choise of effect criteria. Concerning upper noise limits for intermittent and continuous noise, a model has been proposed by Griefahn (20) suggesting that to avoid awakenings from intermittent noise, the maximum noise level should not exceed 53 dBA and to protect from minor sleep alterations, the maximum level should not exceed 47 dBA. For contiunous noise a level between 37 - 40 dBA should not be exceeded. According to the results by Vallet (14), these guidelines would not protect from cardiac responses to intermittent noise. Kozarny (11) suggests that noise levels outside nursery shools should not exceed 60 dBA Leq to protect the sleep of children. A paper by Altena *et al*, this conference. will discuss upper limits in relation to effects on the immune system.

Long term effects of countermeasures

So far. one field survey has been reported after (26) long term countermeasures has been taken to reduce road traffic noise exposure. When heavy vehicles were prohibited during night from 20.00 to 07.00, the night-time Leq-level was reduced by 5 dBA. The number of heavy vehicles dropped from about 200 to 100, and the number of events exceeding 50 and 55 dBA (inside) was reduced to 274 and 24 events, respectively. The after-study, one year after the (not altogether successful) prohibition of heavy vehicles during night, revealed no positive effects according to sleep quality or psycho-social wellbeing. This was apparently due to the fact that even if the number of high noise events was reduced during night, there were still enough noise events to induce sleep disturbances. The missed improvement was perhaps also due to the fact that the noise became less continuous and the distance between Leq (or the L_{90}, L_{50}) and the maximum levels (L_1) increased. Also, the noise exposure during evening and day, which was unchanged, could have affected the nights sleep (23).

Comments

The results mentioned in this report, clearly demonstrate the need for preventive measures against noise as well as evaluation of the effects of these countermeasures. There is still a need for more studies on several of the issues considered as important in the earlier ICBEN-congress, e.g. vulnerable groups such as ill people. Effort should also be put on finding predictive determinators for health effects. Except for cardiovascular reactions, the transient arousal reactions are promising since they can be linked to noise level as well as subjective sleep quality and noise sensitivity.

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THE INFLUENCE OF NIGHT-FLIGHT NOISE ON SLEEP: CHANGES IN SLEEP STAGES AND INCREASED CATECHOLAMINE SECRETION *)

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The effects of aircraft noise on sleep quality were studied on 40 healthy adult subjects during 200 experimental nights in a sleep laboratory [1]. The subjects lived in the vicinity of an airport thus they were exposed to day-time aircraft noise.

The following two factors were varied:

1.) The number of flights per night [16, 32, 64 flights with a maximum indoor sound level of L_{max} = 75 dB (A)] and no flights for the control group.

2.) The temporal distribution of the flights during the sleeping time (five variations).

In order to determine the sleep stages the electrophysiological data EEG, EOG and EMG were recorded for each subject and for each night. The potential inter-relationship with daytime noise exposure, personality traits and general day-to-day conditions were reflected upon as control variables.
The group participating in the experiment without noise exposure spent a second week (5 nights) in the sleep laboratory, exposed to various sound conditions [16, 32 and 64 flights with an indoor sound level of L_{max} = 75 dB (A) and 64 flights with L_{max} = 65 dB (A) and 55 dB(A)].
In addition to the electrophysiological data, the secretion of catecholamines (adrenaline, noradrenaline) was measured after each night during two experimental weeks.

The study reveals that night-flight noise [16 to 64 flights per night with L_{max} = 75 dB (A)] leads to an irregular increase of awakening reactions and to a distinct change of the sleep stage distribution. The significantly shortened sleeping time during the stages 3 and 4 is to be seen as a decrease of the sleep quality, which can be observed when the equivalent sound level L_{eq} exceeds 36 dB (A). The temporal pattern of the nocturnal flights affects the sleep stage distribution as well: The mean duration of each stage time may be moderately changed.

The adrenaline secretion is significantly higher under noisy conditions. Taking into account individual personality traits and general day-to-day conditions, significantly higher mean values for both catecholamines were obtained for noisy nights (60% increase of adrenaline and 17% increase of noradrenaline secretion).
The increase of adrenaline secretion can already be observed at an indoor sound level of 55 dB and 64 flights per night.
The catecholamine secretion increases with the sound level and presumably with the number of flight events. Furthermore, an inter-relationship analysis shows a close link between adrenaline secretion and the sleep stage distribution.

*) An earlier version of this paper was presented at the meeting of the KNMG in Rotterdam, 10th September 1992.

2. Introduction

One basis of an "objective" assessment of sleep quality is the distribution of sleep stages, measured by electrophysiological data (EEG, EOG, EMG). The stages of deep sleep (stages 3 and 4), dream sleep (or REM-sleep) and the waking periods are particularly important. Shorter time of deep sleep and REM-sleep stages and increased waking periods prove a decrease in sleep quality.
Furthermore, a decrease of sleep quality is usually related to an increase of awakenings, movements, sleep-stage changes and enlarged latency times (onset of stage1,4 and REM).
A deterioration of sleep quality over longer periods of time is regarded as a health risk, but it is difficult to verify it empirically, for it may take years for a probably noise-induced effect to manifest itself.

A way to approximate the health damaging potential of noise is to examine noise-induced "primary effects" (short term reactions), if these reactions can be related as medically relevant to the long-term effects on health.

The amount of catecholamine secretion examined in this study fulfils these conditions: An increase of nocturnal catecholamine secretion means an increase of secondary risk factors for the cardiovascular system and may cause negative long-term effects on health. The catecholamine secretion indicates a noise-induced physiological stress reaction [2].

3. Purpose of the study

The purpose of the study is to examine the extent of sleep disturbance of people living near airports through nocturnal aircraft noise and, to evaluate the health-risks induced by aircraft noise.

The following questions were examined:

A. The relationship between sleep quality and number of flights per night [0, 16, 32, 64 flights with a maximum indoor sound level of L_{max} = 75 dB (A)].

B. The relationship between sleep quality and the temporal distribution of the nocturnal flights.

C. The relationship between nocturnal noise exposure and catecholamine secretion.

D. The relationship between catecholamine secretion and sleep quality.

4. Important aspects of the test design

40 healthy and normal hearing subjects (age 18 to 40 years) stayed five consecutive nights in the sleep laboratory of the Institute of Technical Acoustics (200 experimental subject nights). During the day time they continued their habitual life. Before the lights were turned off, a questionnaire about the daily stress was filled in. At night time the electrophysiological data EEG, EOG, EMG were recorded during a period of eight hours. Three of the four experimental groups were exposed to realistic night-flight noise [16, 32, 64 flights per night with a maximum indoor sound level of L_{max} = 75 dB (A)], and the fourth group (control group) was kept aside to nocturnal noise [L_{max} < 30 dB (A)]. The temporal distribution of the nocturnal flights was changed from one night to the other and labeled as follows:

"Evening flight"

50% of the events were distributed equally over the total sleeping time of 8 hours. The other 50% were used for the testing during the first 2 hours of sleep.

"Morning flight"

50% of the events were distributed equally over the total sleeping time of 8 hours. The other 50% were used for the testing during the last 2 hours of sleep.

"Night-flight"

The flights were distributed equally over the total sleeping time of 8 hours.

"Evening/morning-flight"

Half of the number of flights were distributed equally over the first two hours of sleep, the remaining half over the last two hours of sleeping time.

"Midnight-flight"

The flights were distributed equally from the third to the sixth hour of sleeping time.

All the subjects of the control group spent five additional nights in the sleep laboratory and were then exposed to various night-flight noise conditions [16, 32, 64 flights per night with maximum indoor sound levels of L_{max} = 75, 65 and 55 dB (A)].

In addition to the electrophysiological data, the secretion of catecholamines (adrenaline, noradrenaline) was measured after each night during the two experimental weeks.

The aircraft noise was transmitted via a sound system. The noise was not only emitted during the sleeping time, but also during the evening and morning time in all rooms accessible to the subjects in order to simulate a realistic situation.

5. Evaluation method

The entire duration of each sleep stage (called stage time) and the amount of catecholamines in the collected urine were used as the dependent variables for the statistical analysis. The sleep stage times and the catecholamine secretion were analysed by using a regression approach (general linear model), since it was expected that the sleep stage times and the amount of catecholamine secretion do not only depend upon the noise conditions but also vary with personality traits and general day-to-day conditions (see Figures 1 and 2).

In order to get a statistically significant structure of the personality traits and general day-to-day conditions a factorial analysis was used for the evaluation of the questionaires. The questionnaire based factors and the measured control variables,such as daytime noise exposure and the temperature in the sleeping rooms, were taken into account.
Moreover, in the first step of the evaluation the "direct" relations between the nocturnal aircraft noise and different kinds of "primary effects" were uncovered with a Path-Analysis [3].

6. Results

- Path Model of aircraft noise induced sleep disturbance-

The important results from the Path-Analysis are the preferable "directly determinations" between the nocturnal aircraft noise and the primary effects. The discern determination between sleep stage shifts and the nocturnal noise shows the relevance of sleep stage shifts for noise induced sleep disturbance. In the case of the awakenings a direct determination is not available. Two chosen Path-Models are shown in the figures 1 and 2.

Fig. 1:

Direct determinations of the sleep stage distribution

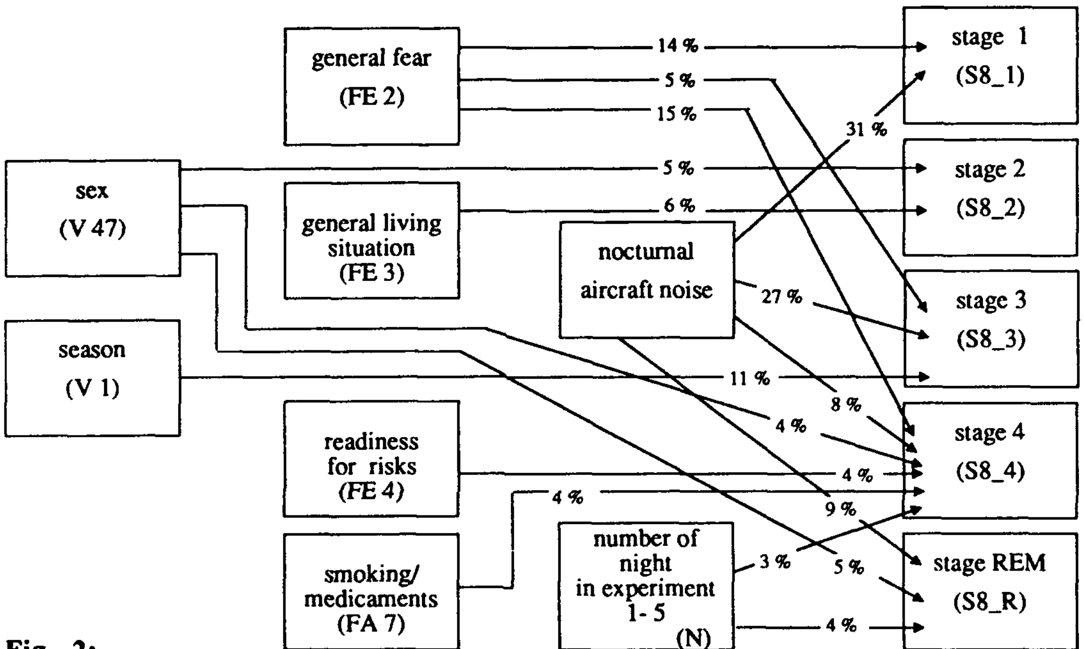
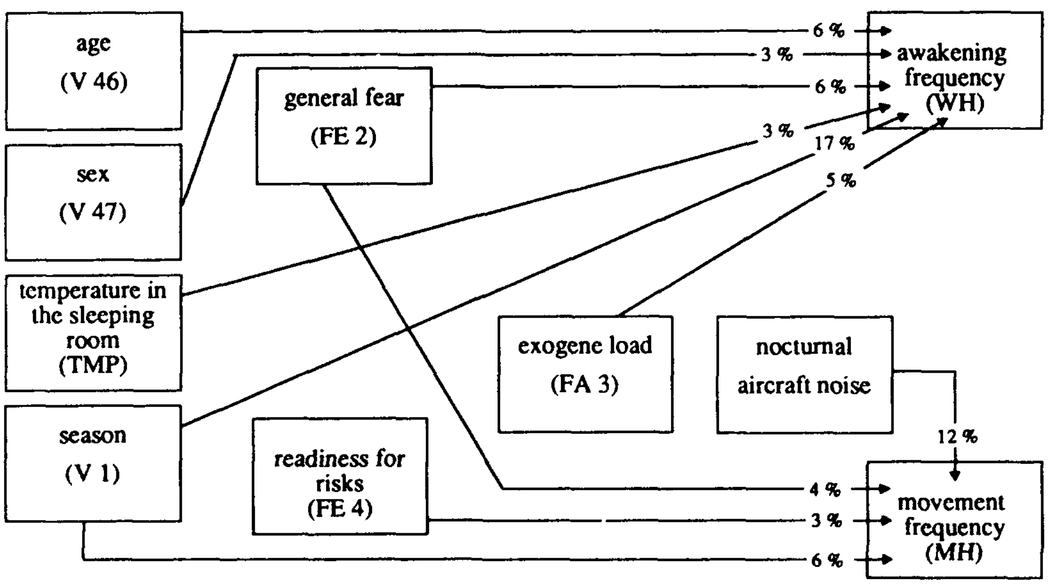


Fig. 2:

Direct determinations of the awakenings and the movements



The sleep stage distribution of subjects exposed to aircraft noise undergoes the following alteration:

The duration of the deep sleep (stage 3 and 4) and of the dream sleep (REM-stage) is shortened to the benefit of the duration of stage 1 (that is falling asleep), periods of being awake and movement time.

Generally speaking deep sleep stages are shifted to shallow sleep stages. The extent of shifts incurred in the sleep stages depend upon the number of flight events. The mean value of the duration of the sleep stages 1, 3 and 4 depends significantly on the number of flight events.

Each flight event with a maximum indoor level of 75 dB(A) decreases the deep sleep time at an average of 0,5 min to the benefit of the "shallow" sleep.
The dependence of sleep stage duration on the number of flight events cannot be explained only by linear trends. A slight square trend can be proved additionally for the sleep stages 3 and 4.

The dependence of mean duration of the stages 1 and 4 on the number of flight events is shown in the figures 3 and 4. Differences between the noise-exposed groups and the control group as well as a systematical change can be shown.

Fig. 3:

Mean time of sleep stages as dependent on the number of flights

stage 1

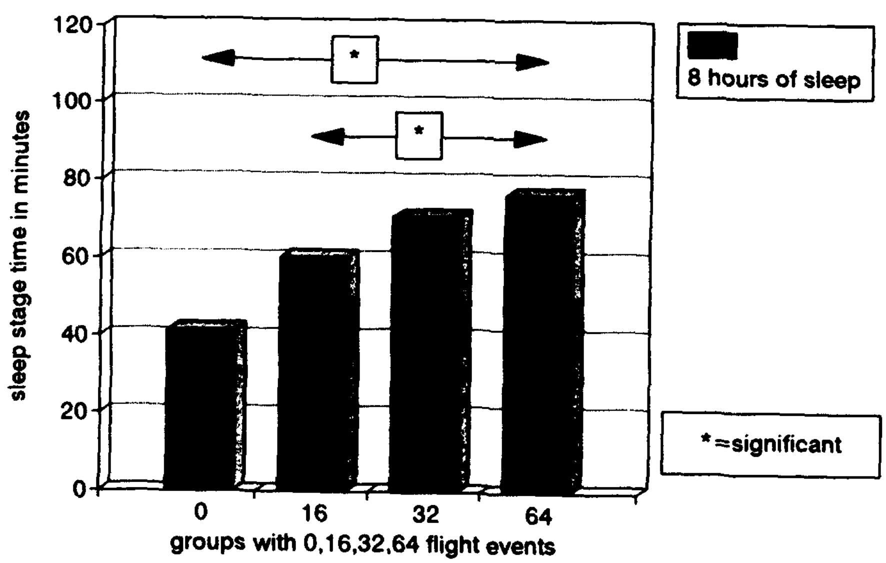
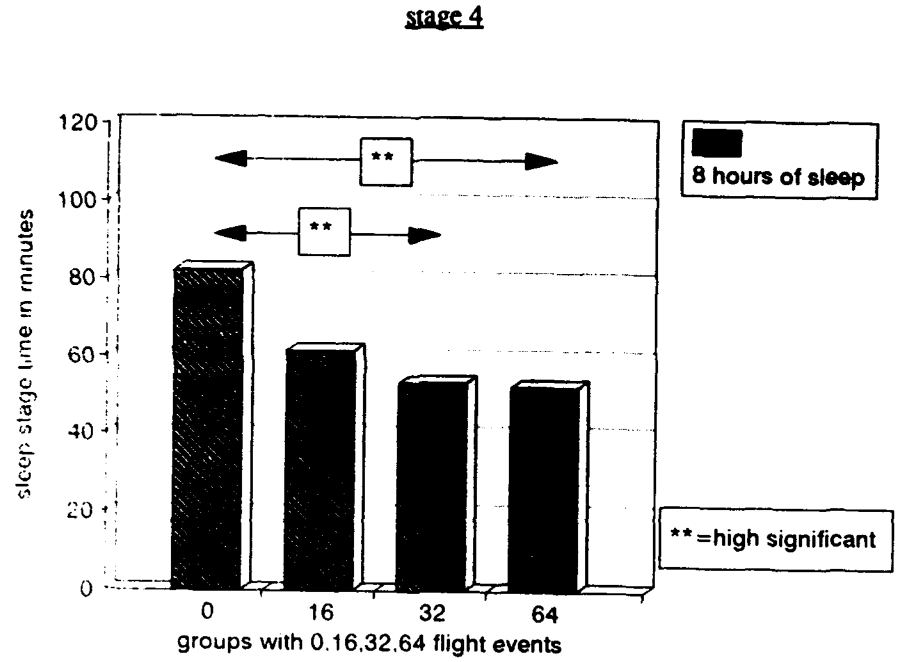


Fig. 4:

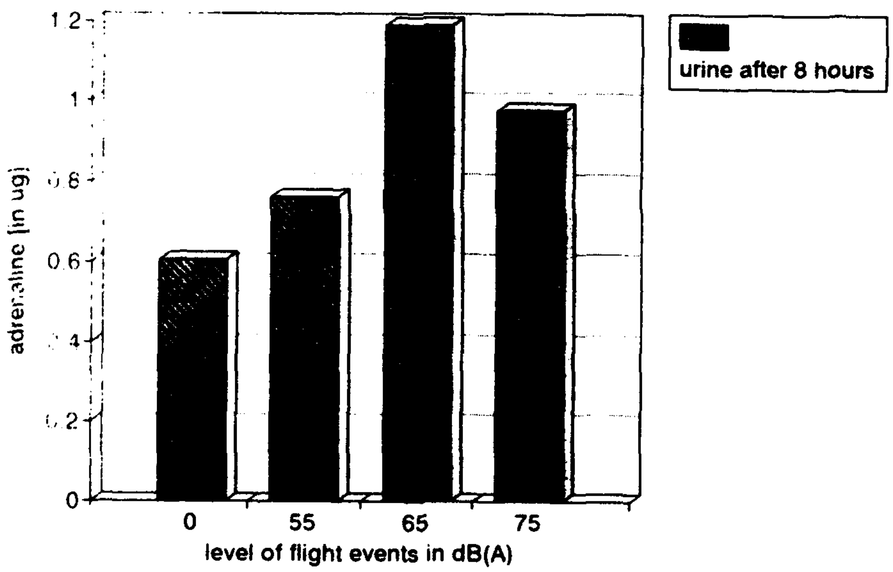
Mean time of sleep stages as dependent on the number of flights



There are distinct differences between quiet and noisy experimental weeks concerning the catecholamine residues (secretion amount cleared from control variable effects, Fig. 5).

Fig. 5:

Cleared amounts of adrenaline as dependent on the level of flight events



An increase of 60% of the mean adrenaline secretion can be proved statistically (S > 95%) under the condition of aircraft noise with an equivalent sound level of 59 dB(A). The noradrenaline secretion residues show an increase of 17%.

— Temporal distribution of the flight events —

The calculated changes of mean stage duration for the morning flight condition are small for all sleep stages and no change of sleep quality can be seen.

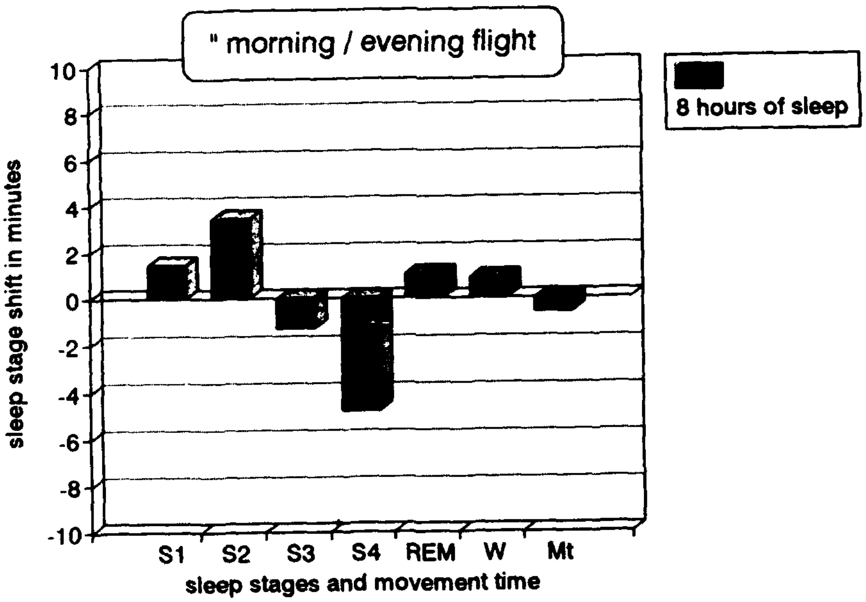
The changes in the sleep stage distribution for the "evening flight", "night flight" and "midnight flight" cannot be valuated homogeneously, because the changes contain elements of improved as well as of decreased sleep quality.

Only under the condition "evening/morning flight" a distinct deterioration of the sleep quality occurs: the deep sleep duration is shorter while the shallow sleep duration is longer (Fig. 6).

Fig. 6:

Deviation of the mean duration of sleep stages

"Evening / morning flight"



Conclusions

The study confirms a significant deterioration of sleep quality caused by intermittant nocturnal aircraft noise [16 - 64 flights per night, L_{max} = 75 dB (A), L_{eq} = 50 - 56 dB (A)].
It can be presumed that changes in sleep stage distribution start to appear at an equivalent noise level L_{eq} of 35 dB (A).
This assumption is proved by the measurement of adrenaline reaction. An equivalent noise level of 36 dB(A) [64 flights per night; L_{max} = 55 dB (A)] leads to an increased adrenaline secretion in the 8-hours collected morning urine

Taking into account the various effects of higher adrenaline level on the cardiovascular system, a long-term nocturnal raise of the adrenaline level must be interpreted as a serious health risk. The study shows that a nocturnal aircraft noise-induced health risk cannot be excluded at levels above 35 dB (A).
The distinct correlation between sleep stage shifts and the increase of adrenaline shows the relevance of sleep stage shifts to health. Hence it should be considered for the definition of noise limits as a basis for nocturnal noise control.

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NOISE DURING DAYTIME SLEEP : EEG DISTURBANCES IN SHIFTWORKERS

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INTRODUCTION

Traffic noises are known to induce significant modifications of global sleep EEG structure. They are even more deleterious when they occur in a period of the nycthemere where the organism is less resistant to stress. It is the case for the shiftworker, whose sleep is often submitted to the combined influence of ambient factors (such as daytime high level of noise) and chronobiological factors (sleeping at unusual times). This situation induces disturbances of sleep whatever the working schedule may be.

A large number of studies have demonstrated the measurable effects of noise on night-time sleep (Williams et al., 1964 ; Griefahn and Muzet, 1978) and on daytime sleep macrostructure (Ehrenstein and Mueller-Limmroth, 1975 ; Knauth and Rutenfranz, 1975) : reduction of slow wave sleep and REM sleep and increase of stage 2 sleep and wakefulness compared to quiet sleep.

Intermittent noises induce also phasic EEG events. The phasic EEG events present three steps of increasing intensity: transient activation phases [*Phases d'activation transitoire* (PAT)] described by Schieber et al. (1971), sleep stage changes (SSC) and awakenings (AW). PAT are phasic events which can be induced by endogeneous stimuli or by external stimuli such as noises. PAT are characterized by a concomitant increase in EEG frequencies, highly variable muscle tone and heart rate increase. These modifications are associated with a transient peripheral vasoconstriction with a subsequent slow return to basal tone. In addition, body movements are often, but not always, associated with these signs (Fig.1). These arousal reactions are probably under the control of the reticular formation.

Moreover, Williams et al. (1964), reported large differences between sleep stage reactivity to noise. As compared to other sleep stage, EEG response show a decrease during Slow Wave Sleep (SWS) and especially during stage 4 sleep. This decrease might be associated to the high proportion of slow waves during SWS but no clear relationship has been found yet.

EEG response to noise was analysed during night-time and daytime sleep in shiftworkers. These responses allowed us to study the variability of the sensitivity to noise with regard to the nycthemeral placement of sleep and the electroencephalographical context of noise occurence. A special attention was taken to characterize the relationships between the responses and the presence of concomitant slow wave background. A noise was considered to be synchronous to slow wave background in NREM sleep (stages 2,3 and 4 sleep), when slow waves were present at least 5 s before the noise peak level.

METHODS

Subjects

14 shiftworkers of the food industry [aged 37 ± 5 years] participated in the study. They were informed about the general nature and the potential risks of the experiment, and gave their signed informed consent.

They were selected on the basis of their seniority in shiftwork [mean seniority : 11 ± 3.5 years], their physical fittness and on the absence of sleep disorders. Their hearing level was similar, when tested between 250 and 8000 Hz by an automatic audiometer. A medical examination verified the lack of any neurological, psychiatric or cardiovascular diseases.

Experimental design and procedure

One experimental series was constituted of four sessions 1) habituation daytime sleep; 2) and 3) experimental daytime sleeps; 4) experimental night time sleep.

In order to respect the usual sleep schedule, the recording sessions were distributed over the reverse three week shift system performed in the factory. The three daytime sleep periods took place during the 1st week (nightshift: work from 2200 to 0600), on Tuesday, Thursday and Friday, respectively (sleep ad libitum from 0800). The experimental night-time sleep was recorded on Thursday-Friday night, during the 3rd week (morning shift: work from 0600 to 1400) from 2200 to 0400. Subjects were instructed to come to the laboratory one hour before the night session or the day sessions. During night-time sleep they had to be awakened at 0400 to go to work, but during daytime session they could sleep *ad libitum*.

Traffic noises were presented during the four sessions. Three types of well defined traffic noises were used: car, motorbike and truck. Their peak intensities were respectively of 64 db(A) for the car noise, 67 dB(A) for the motorbike noise and 71 dB(A) for the truck noise. Each noise was merging from a stable background noise (filtered pink noise) of 35 dB(A). Noises were semi-randomly distributed at a rate of $9.h^{-1}$ (8 noises of each type per repetitive sequence of 150 min) to produce an usual low road traffic (L_{eq} 2200-0800: 49 dB(A)). Their respective duration was of 19 s for motorbike noise and of 10 s for car and truck noises. Spectral and dynamic acoustic treatments have been applied to original digital recordings of the three types of vehicles passing at an average speed of 60 $km.h^{-1}$, on a road located about 20 m away from the microphone. Each type of noise differed in intensity, duration, rising time and spectral composition. Thus, analysis of the influence of intrinsic characteristics of noise on EEG and cardiac responses was possible.

The diffusion of noises was performed by two tape recorders (Revox B77 Mk II), six amplifiers "Mos-Fet" of 200 W rms and two loud-speakers (harmonic distortion: 1% at 100 dB, band pass: 30-20,000 Hz) placed at 3 m from the head of the subject.

Data analysis

Analyses of variance for repeated mesures (ANOVA: BMDP 2V program) were used to test the data according to theory of Vasey and Thayer (1987), using the Geisser-Greenhouse coefficient (1958) for overall F values. Statistical analysis were performed on individual data. Each subject served as his own control. Differences between the responses to the three types of noise, or according to the different EEG backround or, lastly, during the two nycthemeral placements were tested by paired Student's t-test when overall F values were significant (Myers, 1979).

The two first daytime sleeps were considered as habituation sleeps. All the comparisons were done between the third daytime sleep and the night-time sleep, the last one being taken as reference condition. All given values are mean ± 1 SD. All analyses of percentages were performed on arcsin transformed data to stabilize the variance (Winer, 1971).

RESULTS

The results show that, compared to night-time sleep, there was some modifications in daytime sleep structure:

- increase of SWS percentage (especially sleep stage 4) and earlier SWS barycenter ;

- decrease of REM cycle duration and REM latencies, and earlier REM sleep barycenter ;

- decrease of stage 2 latency.

Motorbike noise produced more PAT, SSC and AW than the other noises during daytime sleep although it was not the loudest. These effects

were less clear cut during night-time sleep. The Car noise remained the less disturbing one.

During night-time and daytime sleep, noises induced more PAT, SSC and PAT+SSC in NREM sleep (sleep stages 2, 3 and 4) than in REM sleep. On the opposite, the percentage of isolated PAT provoked by noise (PAT without any other EEG event) was higher in REM sleep than in NREM sleep (fig. 2).

Daytime REM sleep was more disturbed by noise than the night-time one, as more EEG events and SSC were induced in this state.

During night-time and daytime NREM sleep, noises occuring within a slow wave background produced less PAT and AW than noises occuring without slow wave background (fig. 3).

~~Nevertheless, the noises occurring during slow wave background provoked the same percentage of EEG response during daytime and night-time NREM sleep. Thus the changes occurring between daytime and night-time slow waves appeared to be more quantitative than qualitative~~.

DISCUSSION

Effect of the type of noise

The motorbike noise provoked the highest percentage of EEG events (PAT, SSC, AW) during daytime or night-time sleep. These results demontrate that the intensity of noise was not a predominant factor as motorbike noise intensity was lower than truck one. It seemed that, in this case, the dynamic aspects (acoustric spectrum, rising time) of the noise could be regarded as most important. These results are consistent with those of Bach et al. (1991) who used the same types of noise. In fact, motorbike noise showed a double cut in its spectrum with a predominance in the low frequencies, while car noise was more regular and truck noise had a spectral composition abundant in high frequencies.

In contrast, isolated PAT were not affected by the type of noise neither during night-time nor during daytime sleep. One explanation could be that this type of low magnitude activation could react as a "all-or-nothing" phenomenon regardless of the type of stimulus.

Effect of the sleep stages

There was a strong sleep stage effect on PAT, SSC and AW but it differs according to the type of EEG events :

- Noises provoked more SSC, PAT+SSC and AW during NREM sleep than during REM sleep.

- On the contrary, noises provoked more isolated PAT in REM sleep than in NREM sleep (especially during SWS) ;

The differences observed between SSC and AW on one part and PAT on another part can be explained by the fact that the activation provoked by noise occurrence during a low activated sleep stage (i.e. stage 4 sleep) would interrupt it and could bring a SSC rather than a PAT (Muzet et al., 1972). So the main type of response would be the SSC for SWS and isolated PAT for REM sleep. Consequently isolated PAT appeared to be a specific phasic event of the REM sleep.

In addition, isolated PAT must be clearly differentiated of the association of PAT+SSC which must be considered as another type of activation. In fact the common notion of low reactivity of the REM sleep could be partly explained by the unapropriate choice of criterion (i.e. SSC and AW) to measure the capability of response of this sleep stage.

Effect of the slow wave background

The difficult differenciation between the reactivity to noise during stage 2 sleep and SWS, in our experiment, led us to consider that the analysis of the EEG macrostructure was not sufficient. Thus we focus on the microstructure of NREM sleep and especially on the presence of slow wave background during noise occurrences.

Within slow wave background, noise provoked less EEG events, than outside. These results are in agreement with those of Berry and Thiessen (1970) who have shown the low sensitivity to noise in stage 3 and 4.

One of the important findings of this study is the possibility to clearly associate the decrease of the reactivity of SWS, and especially stage 4 sleep, and the presence of slow waves. This fact could be an explanation of the high variability of response during SWS, probably due to variations in the number of slow waves present in different SWS periods. Talking about the reactivity of stage 2 or stage 3 sleep become therefore questionnable. In fact responses are strongly dependent on the presence of slow wave background but loosely dependent of NREM sleep stage.

Effect of the nycthemeral placement of sleep

The lack of global modification of the percentage of provoked EEG events is explained by the fact that the increase of the number of EEG events during daytime REM sleep was compensated by a slight decrease of EEG events during SWS and stage 2 sleep.

The influence of the inversion of the sleep/wake rhythm on EEG response to noise is totaly explained by the changes of the sleep structure.

The decrease of daytime SWS reactivity matches with the increase of stage 4 sleep percentage, which is known to be less disturbed by noise. This lower reactivity to noise can be correlated to its high concentration of slow waves. Nevertheless, the noises occurring during slow wave background provoked the same percentage of EEG response during daytime and night-time NREM sleep. So the changes between daytime and night-time slow waves appeared to be more quantitative than qualitative.

The changes in REM sleep reactivity seem to be influenced by circadian factors. Actually, REM sleep episodes occurring in the last sleep cycle has been found to be more reactive than those occurring in the first sleep cycle (Lukas and Kryter, 1968). In our study, daytime REM sleep was generally initiated around 0900 and could be considered as a "end-of-night REM sleep" as 0900 is near the period where the sleep normaly ends.

CONCLUSION

In conclusion, reactivity to noise during sleep depends not only on the type of noise and on sleep stage, but also on the EEG background where the noise occurs and the period of the day where sleep is taken.

This work was supported by the French Ministry of Environment (contract n° 89-248).

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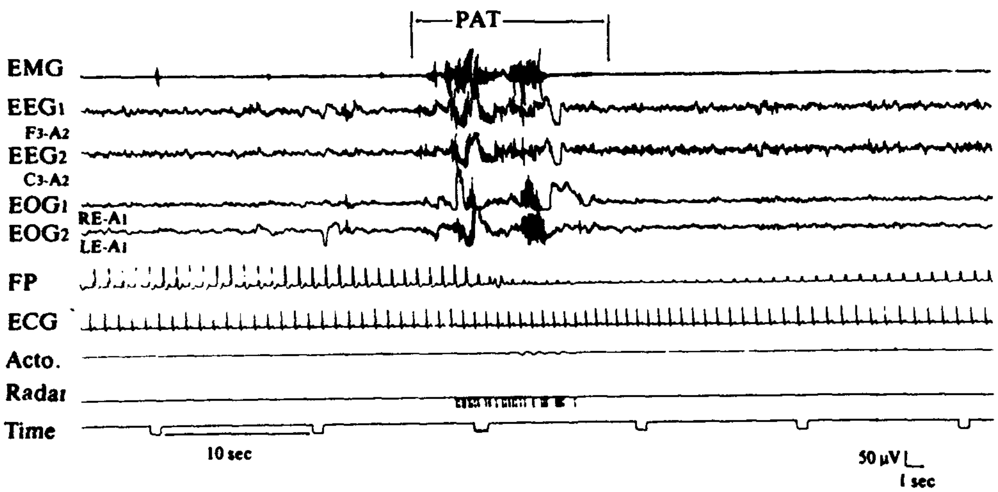
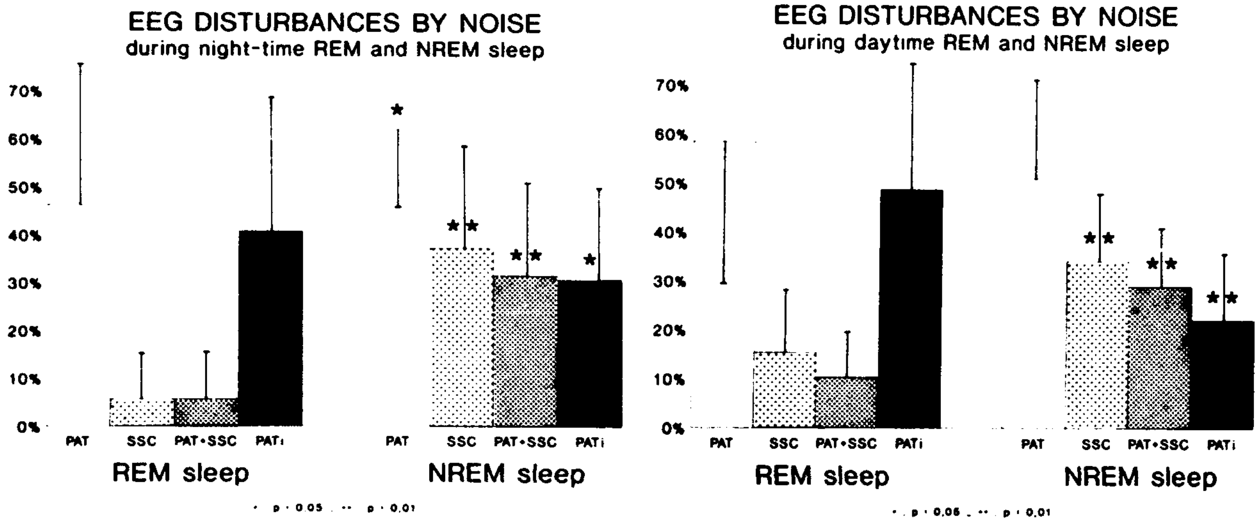


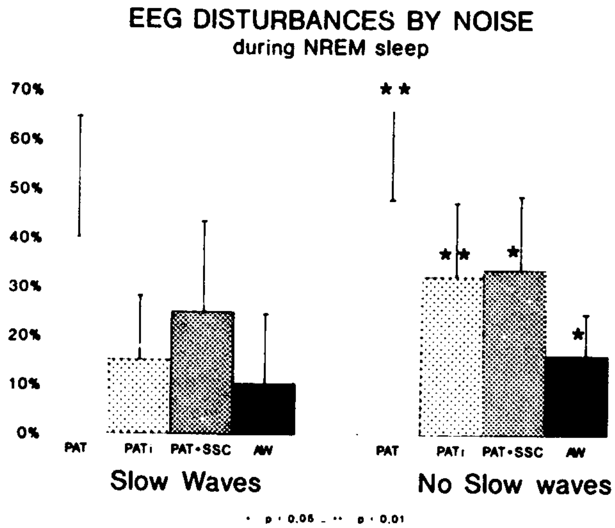
Legends :

Fig 1 : Example of a "Phase d'Activation Transitoire" (PAT). EMG, electromyogram; EEG, electroencephalogram; EOG, electro-oculogram; RE, right eye; LE, left eye; FP, finger pulse; ECG, electrocardiogram; Acto, Actographic bed.

Fig 2 : EEG disturbances by noise during night-time and daytime sleep : percentage of EEG events provoked by noise. The significant différences appear in the comparison between percentage of EEG events provoked by noise during REM sleep and during NREM sleep. PAT, phases d'activation transitoire; SSC, sleep stage changes; PATi, isolated PAT.

Fig 3 : EEG disturbances by noise during NREM sleep : percentage of EEG events provoked by noise. The significant différences appear in the comparison between percentage of EEG events provoked by noise during REM sleep and during NREM sleep. PAT, phases d'activation transitoire; SSC, sleep stage changes; PATi, isolated PAT.





AIRCRAFT NOISE AND SLEEP DISTURBANCE: A UK FIELD STUDY

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Introduction

Where possible, it is government practice in the UK to base aircraft noise policy decisions on relevant scientific research. The role of the CAA in this area is to carry out research, especially on the effects of aircraft noise on people living near airports, and to provide technical advice to the Department of Transport (DOT) which has responsibility for administering government policy. Since 1962, it has been policy to restrict night flights at London's airports. The current flight quotas, introduced in 1988, were based in part on the results of studies conducted by the CAA between 1977 and 1984 (Refs 1-3).

The first of these studies was a review of then available literature on noise induced sleep disturbance, much of it based on laboratory studies. From this, and especially an analysis performed by Lukas (Fig 1), it was concluded that although there is no threshold of awakening, ie the proportion of people wakened by noise simply increases steadily with noise level, outdoor noise events of 90-105 EPNdB would not disturb most people asleep indoors†† (Ref 1).

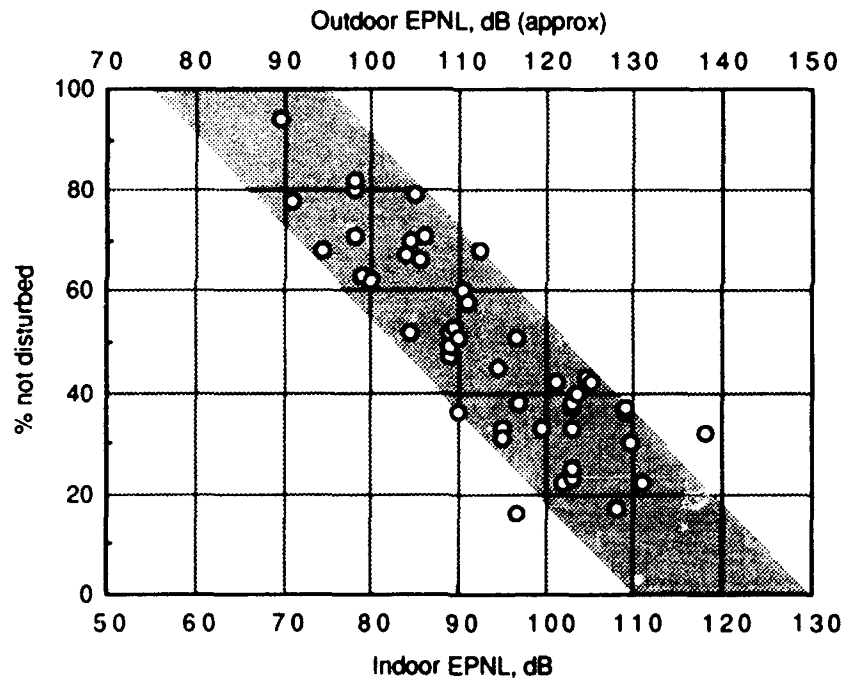

Figure 1 - Sleep disturbance as a function of event noise level (After Lukas, Ref 4)

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* Now with AEA Ltd

† This paper describes the views of the authors. It should not be construed as reflecting official CAA or DOT policy

†† A consequence of this finding was that when the London airports' noise insulation schemes were updated in 1980 and 1989, the scheme boundaries were extended to encompass the 95PNdB 'noise footprints' of aircraft flying at night.

Questions considered to remain unanswered were (a) whether laboratory studies represent the real impact of people sleeping at home, (b) how aircraft noise ranks alongside other causes of sleep disturbance and (c) would peoples' subjective assessments of sleep interference aid in providing a valid criterion for permissible night noise exposure?

To throw additional light on these questions, a three-year social survey study was subsequently performed near London's airports at Heathrow and Gatwick. A specific aim was to investigate the relationship between aircraft noise exposure and sleep disturbance. The approach was to interview samples of residents living within 'common noise areas' where outdoor aircraft noise exposure was essentially uniform. Data were collected in 1979 from 25 such areas via 964 interviews and 3188 postal questionnaires (Ref 2).

Among the the conclusions were that:

(1) Leq(8-hr) for the period 2300-0700 is a satisfactory measure of aircraft noise exposure, ie one which correlates well with sleep disturbance.

(2) Total disturbance of sleep, irrespective of cause, showed a slight increase at higher Leq levels. The proportion of people who say they are wakened more than once a week increased from ~30% at 40dBA Leq to ~40% around 65dBA. The increase in total disturbance only became detectable above sampling fluctuations for sites with Leq ≥ 65dBA Leq.

(3) The incidence of disturbance attributed to aircraft noise increased more noticeably with Leq. At 65dBA about half of those awakened blamed aircraft noise compared with ~10% at 40dBA.

It was noted that levels of 65dBA Leq were only experienced (at that time) at locations where some aircraft noise event (ANE) levels exceeded 90dBA Lmax and that it was difficult to disentangle the contributions of event levels and event numbe[illegible] However is was stated that "the study provides no evidence to indicate that an increase of 25% [illegible]) in 'quiet' movements could be deleterious provided that the number of noisy movements is reduced to ensure that Leq is not increased".

A further 'Check Study' was conducted in 1984 (Ref 3). The methodology of this study was unchanged but the scope was reduced - 300 people were interviewed at two sites and a postal survey was made of 1000 residents living at five sites. The sites were among the noisiest of those studied previously.

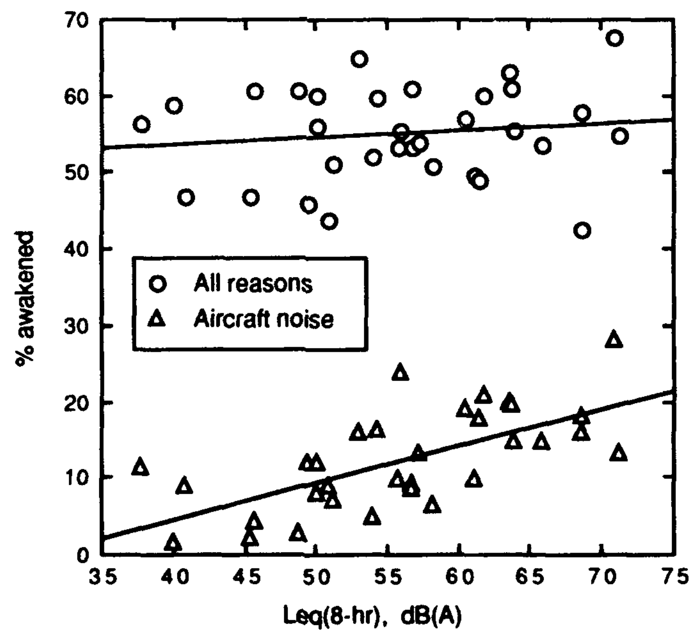

Figure 2 - Awakenings reported in the 1979 and 1984 CAA surveys (Refs 2 and 3)

Figure 2 shows the results of the two studies in a graph of % awakened v Leq(8-hr) at each of the study sites. This clearly illustrates conclusions (2) and (3), which the Check Study tended to confirm (with the exception that, due to a general lowering of aircraft noise level during

the intervening years, the significant increase in total disturbance at ≥65dBA Leq had become difficult to detect).

When the Heathrow and Gatwick night restrictions were revised in 1988, for a period of five years, modest increases in the total number of night flights were allowed at Gatwick. However, the new quota system was devised to ensure that the gradually changing mix of noisier and quieter aircraft would prevent any increase in total night noise exposure, as measured in terms of Leq.

The 1991 Study aims

As the policy was due to be reviewed again in 1993, the Department of Transport asked the CAA to undertake fu. ʰɜr studies of aircraft noise and sleep disturbance, with emphasis on objective measurements. The study has been conducted by research teams from the Universities of Loughborough, Manchester Metropolitan and Southampton and the CAA (Ref 5). Some of the details are described in companion papers (Refs 6-9); this paper describes the study in broad terms.

The main objective of the new study was to determine the relationships between outdoor aircraft noise levels* and the probability of sleep disturbance. Because measurements of sleep disturbance show a large amount of variation between individuals, large data samples are needed to distinguish between the effects of different sources of disturbance. There is also evidence of a substantial lack of agreement between field and laboratory data (Fig 3). This raised concerns that, although further laboratory studies could be designed to provide more controlled test data on the effects of aircraft noise on sleep, uncertainties would remain about their re'ᵊvance to 'real life' situations. From this point of view, a large scale field study was preferable.

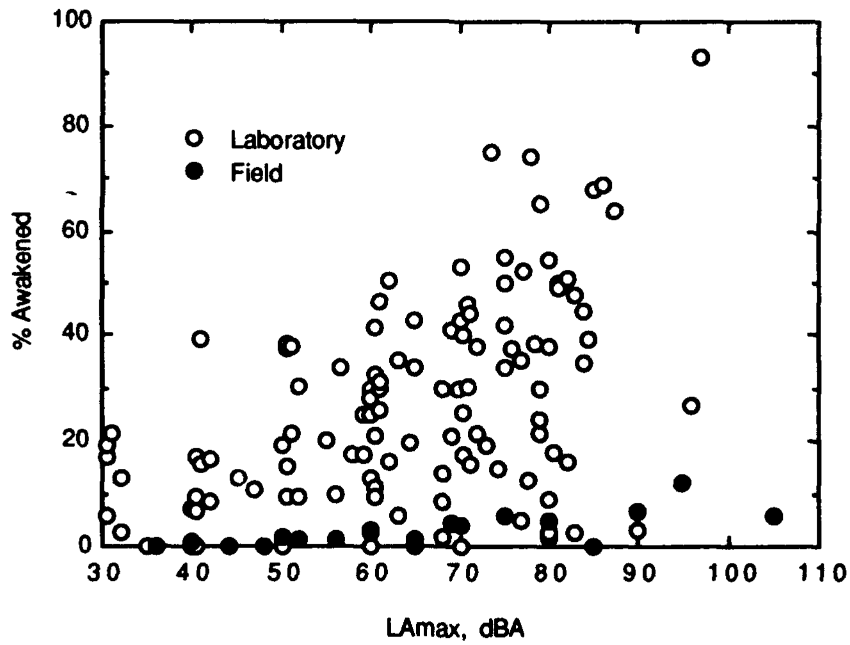

Figure 3 - Noise induced awakenings - Laboratory and field data (after Pearsons, Ref 10)

* Although people in bed hear aircraft noise as attenuated by the walls, windows and furnishings of their bedrooms, indoor noise levels naturally vary very widely from room to room and from ear to ear. These variations cannot be accounted for in planning or policymaking; only outdoor levels are known or can be estimated with any degree of confidence. Noise level measurement inside all subjects' bedrooms was not practicable. The unknown variability is viewed simply as one of the many uncontrollable factors affecting sleep disturbance.

Because of its high cost, EEG monitoring was not a practical option and it was decided instead to use actimeters for the bulk of the field measurements. Actimeters are small, relatively inexpensive devices, worn like a wrist watch to record fine limb movements which are indicative of sleep disturbance, and easily used in the home without supervision. Actimetry is widely used in sleep research, but an important part of the study was to validate its use for measuring the effects of aircraft noise on sleep by direct comparison of EEG and actimeter measured disturbance.

Definition of sleep disturbance

Although opinions differ on precise definitions, there appears to be broad agreement that any identified period of EEG-measured wakefulness is clearly indicative of sleep disturbance. Accordingly, for the purposes of this work, an EEG-disturbance was defined as an episode of wakefulness lasting 15 seconds or more, or 'movement time' lasting 10 seconds or more. Onsets of such disturbances, identified from EEG records are defined as *awakenings*.

Disturbances identified by actimetry, ie any onsets of wrist movement following still periods, are termed *arousals*. Most of these arousals were found to coincide with EEG *awakenings* but they also include many lesser perturbations.

Measurements

In the main study, volunteer subjects were recruited from homes in 8 'common noise areas', two near to each of four major UK airports. The sites were chosen (a) to cover a wide range of nighttime aircraft noise exposures (Leq) and widely different combinations of event noise levels and numbers, (b) to be large enough to provide statistically adequate samples of residents but small enough to limit the variation in outdoor noise exposure, and (c) to be free of excessive noise from non-aircraft sources.

The fieldwork was conducted during the summer of 1991. At each site, 200 people were interviewed in a preliminary social survey. As well as providing a pool of potential subjects, the social survey was designed to yield information on factors in addition to noise which affect sleep patterns. These included personal characteristics, general views about the neighbourhood, perceptions of sleep quality and the ways in which that might be affected by aircraft noise. At each site, 50 subjects selected from the survey respondents wore actimeters for a fifteen night monitoring period; 6 of them also underwent simultaneous EEG monitoring on four sequential nights. All subjects also completed sleep logs and daytime diaries. In all, 400 subjects were monitored for a total of 5742 subject-nights. Sleep-EEG were obtained from 46 subjects for 178 subject-nights. Some 40,000 subject-hours of sleep data were analysed, broken down into more than 4.5 million 30-second *epochs*. Outdoor aircraft noise levels (Lmax and SEL) were measured at each site using noise monitors set to record all levels in excess of 60dBA. A total of 4823 aircraft noise events were logged during 120 measurement nights at outdoor noise levels from 60 dBA to more than 100 dBA Lmax.

Findings

For the EEG-sample, the agreement between actimetrically determined *arousals* and EEG-measured *awakenings* was very good: 88% of all awakenings coincide with actimetric arousals. For the noisiest site, the agreement was 92%. The agreement in the case of undisturbed epochs is even higher, 97% overall . This is important support for the actimetry method, given that undisturbed epochs were 95% of the total.

The mean arousal rate (ie the proportion of epochs with movement arousals) for all subjects, all causes, all nights, all epochs, was 5.3%. For the average sleeping period of 7 hours, this is equivalent to about 45 arousals per night. Of these, some 40%, ie about 18 per night, are likely to be awakenings of 10-15 seconds or more, the remainder being minor perturbations .

Individual rates of sleep disturbance varied markedly; after statistically controlling for the effects of aircraft noise, sex and time of night, the 2-3% most sensitive individuals were disturbed over 60% more than average. There appear to be no strong personal factors contributing to this sensitivity; a large number of possible variables have been specifically ruled out , although further analysis is being undertaken.

Figure 4, shows the *estimated disturbance rate for an individual of average arousability* as a function of outdoor sound exposure level (SEL). The results indicate that, below outdoor event levels of 90 dBA SEL (80 dBA Lmax), aircraft noise events (ANEs) are most unlikely to cause any

measurable increase in the overall rates of sleep disturbance experienced during normal sleep. For outdoor event levels in the range 90-100 dBA SEL (80-95 dBA Lmax) the chance of the average person being wakened is about 1 in 75. Only at higher ANE levels do the prediction intervals exclude the non-ANE arousal rate. Again, individual deviations from the average are substantial. It is possible that, for aircraft noise related disturbance, the variability is even greater; compared with the average, the 2-3% most sensitive people could be over twice as likely to be disturbed and the 2-3% least sensitive less than half as likely.

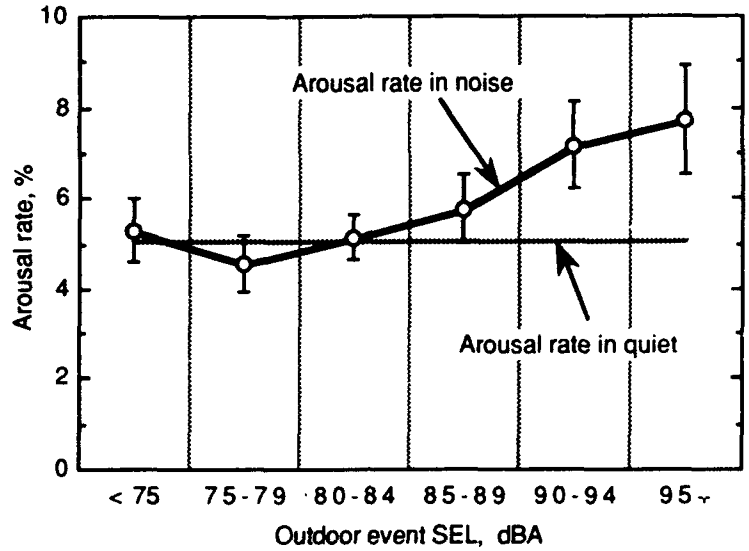

Figure 4 - Relation between actimetric arousal rate and aircraft noise level (Error bars show 95% prediction interval)

Overall, men were disturbed from sleep about 15% more frequently than women and that this is true for all causes of disturbance, not especially aircraft noise. No statistically significant effects of age were found.

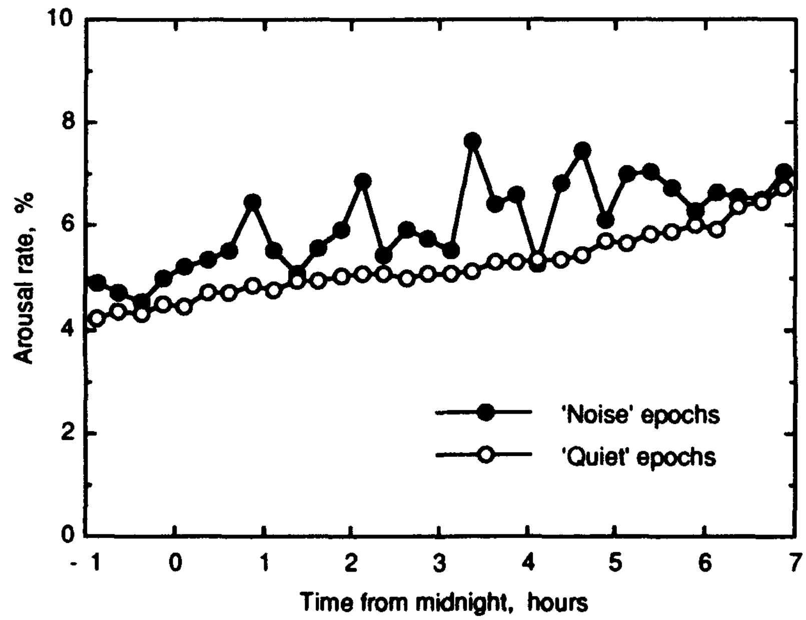

Figure 5 - Variation of actimetric arousal rates with time of night

The data are broken down by time of night in Figure 5, showing that the overall disturbance rate increases steadily, from the equivalent of about two awakenings an hour at the beginning of the night to about three per hour at the end of the night. Arousals related to aircraft noise fluctuate with time. Although difficult to verify statistically, natural biological rhythms of sleep may be the reason.

Recollections of sleep disturbance

For 57% of subject-nights, no awakenings were reported the next day. On the remaining 43% of occasions, at least one awakening was reported (all causes), the average number being three per night. In 26% of reported awakenings, the reason was 'not known'. For the remainder, the most frequently reported cause was 'toilet' (16%). The next most common was 'children' (13%), mainly among younger women. 'Illness' was also mentioned frequently (>9%), again mostly by women. 'Aircraft' was a relatively minor cause (<4%); about one quarter of all actimetry subjects specifically reported being disturbed by aircraft noise during the study - on average by these subjects, once every five nights.

The agreement between individuals' measured arousal rates and their general self-ratings of sleep quality (recorded during the prior social survey interview) was poor. However, there was better agreement between the measured arousal rates and next-day reports of sleep quality obtained from the daily sleep logs. This suggests that when social survey methods are used for investigating sleep disturbance, emphasis should be placed on collecting data about disturbance experienced during the previous night (as was the case in Figure 2).

Conclusions

The two main conclusions which emerge from the study are (a) that actimetry provides a very cost-effective way of measuring arousals from sleep in people at home and (b) that aircraft noise is a relatively minor cause of these arousals.

The results relate only to disturbance from sleep; they do not answer the question of whether aircraft noise delays sleep onset, at the beginning of the night, after awakening during the night, or after premature awakening in the early morning. The measurements of sleep disturbance also are quite distinct from those of annoyance that disturbance may cause.

Within these limits, the results do support those of the earlier studies. The sleep disturbance threshold outdoor noise level of approximately 90dBA SEL conforms with that of 95EPNdB inferred from Figure 1 and the 1/75 probability of disturbance by ANEs in the range 90-100dBA SEL outdoor (~60-70dBA Lmax indoors) aligns with the field data in Figure 3. Furthermore, although it may be largely coincidental, if all ANEs greater than 90dBA SEL recorded in this study caused an awakening rate of 1 in 75, the total resulting awakenings would have numbered 336. This is remarkably close to the 346 reported awakenings that were actually attributed by the subjects to aircraft noise disturbance.

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EFFECTS OF LOW LEVELS FROM ROAD TRAFFIC NOISE DURING NIGHT - A LABORATORY STUDY ON NUMBER OF EVENTS, MAXIMUM NOISE LEVELS AND NOISE SENSITIVITY.

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SUMMARY

The paper presents a laboratory study on the effects on sleep of exposure to different number of events from road traffic noise with a maximum noise level of 45 dBA. Twelve test persons slept eight nights under home-like laboratory settings. All test persons considered themselves as rather or very sensitive towards noise. The full results from the experiment will be published elsewhere. Here the results on subjective sleep quality and body movements are reported. The main results were a significant decrease in subjective sleep quality at 32 noise events per night. At 64 noise events 50 % of the test persons experienced difficulties in falling asleep and, as compared with quiet nights, the time required to fall asleep was prolonged with 12 minutes on average.

INTRODUCTION AND AIM

The aim of the laboratory study was to elucidate the importance of number of noise events with a relatively low maximum noise level for sleep disturbance effects (body movements, subjective sleep quality, mood and performance) among relatively noise sensitive subjects. This L_{Amax} level was chosen since the Swedish Environmental Protection Board has suggested a limit for road traffic noise during night (19:00 - 07:00) of 45 dBA. A second aim was to compare the results from this laboratory study with earlier experiments with maximum noise levels of 50 and 60 dBA involving 28 subjects who estimated themselves as rather or not very sensitive to noise.

METHOD

Test persons.

Twelve test persons slept eight consecutive nights under home-like laboratory settings. All test persons (aged 20 to 42 years) considered themselves rather (eight

subjects) or very sensitive (four subjects) towards noise.

Noise exposure.

During four of the nights, the test persons were exposed to 16, 32, 64 and 128 noise events from recorded road traffic noise at a maximum noise level of 45 dBA. The frequency was centered around 250 Hz. The exposure was started at 22:30 and continued until 07:30. The lights were turned off at 23:00 when the subjects went to bed. In the morning the test persons were awakened by an alarm clock at 07:00.

Evaluation of effects.

Body movements were measured with an accelerometer fastened to the bed. Large and small movements were measured and stored in parallel with the noise events. A questionnaire was used to measure time to fall asleep, number of awakenings, subjective sleep quality (100 mm scale) and tiredness evening, morning and day. Mood was measured every evening and morning in terms of extroversion, activity, wellbeing and relaxation.
Two 10-minutes performance tests were completed evenings and mornings - a simple vigilance test (SAM-5) and a 3-choise reaction time test with a memory component.

RESULTS

Body movements

Acute effects.

The noise periods during a night were defined as 20 second periods with a noise event from the reported time to fall asleep to the final awakening in the morning for each subject. Three times more movements per minute were found during the noise periods as compared to the quiet periods between the noise events. During the sleeping period 28 to 40 % of the noise events were followed by a body movement.

At higher noise levels in earlier studies (50 and 60 L_{Amax}) the same proportion of the noise events caused a body movement.

Whole night effects.

The total number of body movements varied between 23.9 and 26.6 per hour during the different experimental nights. The number of large movements per hour varied between 9.5 and 11.2 per hour. There was a large variation in number of movements between different individuals (sd= 4.1 - 6.6 for large movements and sd=10.6 - 12.3 for total number of movements per hour).

Figure 1 shows the number of body movements per hour during the different experimental nights.

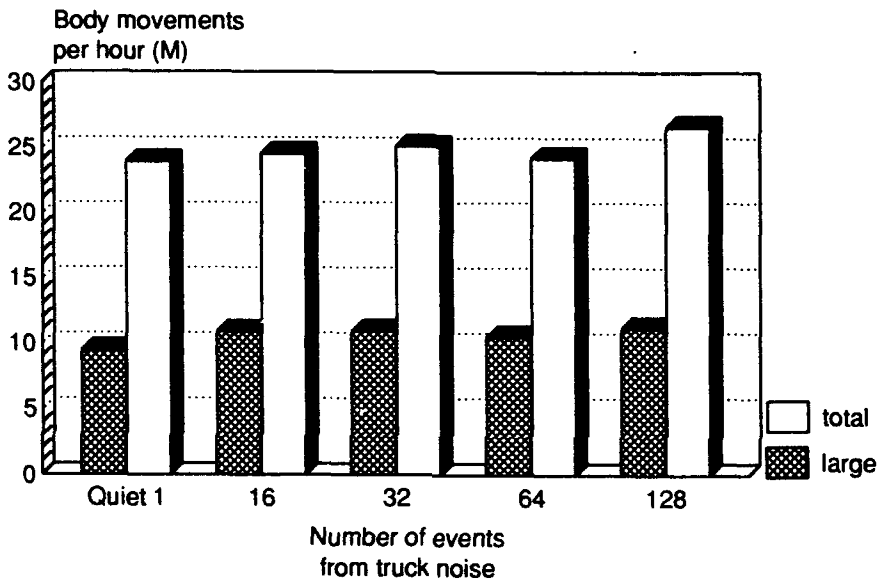

Figure 1. Number of body movements per hour during the different experimental nights.

A slight increase in number of large movements during the noisy nights was seen as compared to the quiet night except for the night with 64 noise events. This increase was not found in the earlier studies with 50 and 60 L_{Amax}.

Subjective sleep quality.

The results from the sleep quality questionnaire are shown in table 1.

Table 1. Sleep quality parameters.

	Quiet	----- 16	Noise exposure 32	----- 64	128
Minutes to fall asleep (M)	21	25	26	36**	36
Difficulties to fall asleep (%)	8	17	25	50▾	42
Awakenings (M)	1.8	1.7	2.1	1.8	2.0
Sleep quality (M)	73.3	69.3	66.4*	60.5**	59.8*
Tiredness Morning after (M)	48.8	48.5	51.6	46.7	47.0
Day after (M)	70.3	55.6*	57.7*	55.3*	56.4*

** $p<0.05$, ** $p<0,01$ Wilcoxon test ▾ $p=0.03$ Fishers test.*

The table shows that time in *minutes to fall asleep* increased significantly at 64 noise events and 50 % of the test persons reported difficulties to fall asleep. At 128 noise events the increase was not statistically significant due to the large variation between test persons.

The average number of *awakenings* was not significantly affected by noise, but the percentage of test persons who were awakened by noise increased with number of noise events.

Subjective sleep quality was significantly decreased from 32 noise events per night.

Tiredness the morning after was not affected whereas a significant increase in tiredness was present during the day after nights with noise exposure.

Comparisons with results from earlier laboratory experiments.

In the following comparisons are presented between the results from this laboratory experiment and earlier experiments with noise levels of 50 and 60 L_{Amax}. In the carlier studies the test persons were rather and not very sensitive to noise and the background noise level was about 3 dB higher due to a higher noise level from the ventilation system.

Figures 2 a - d show comparisons for the different effects on (a) difficulties to fall asleep, (b) number of awakenings, (c) percentage of test persons who were awakened by noise and (d) subjective sleep quality. The curves represent mathematical approximations of the observation points.

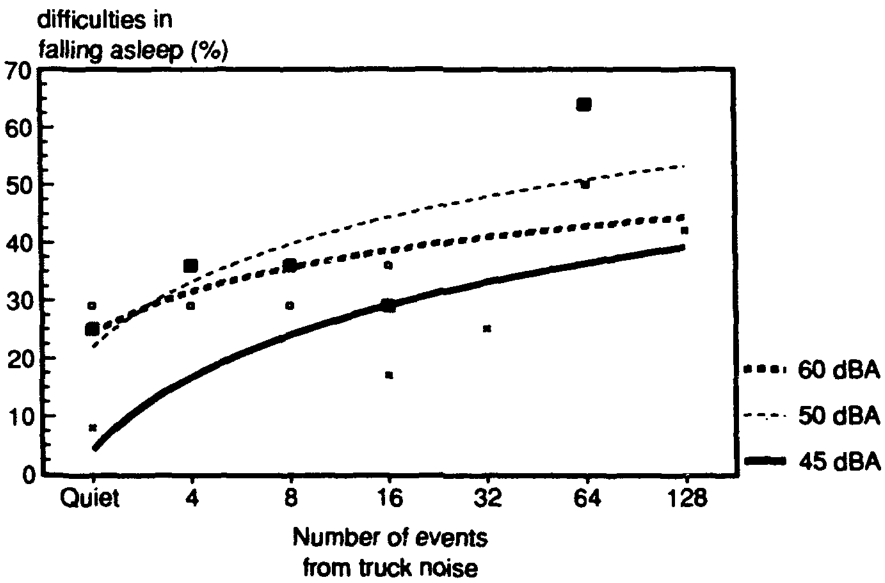

Figure 2 a. Difficulties falling asleep at different L_{Amax} levels.

The figure indicates that the *number* of noise events seems to be more important for difficulties to fall asleep than the noise level.

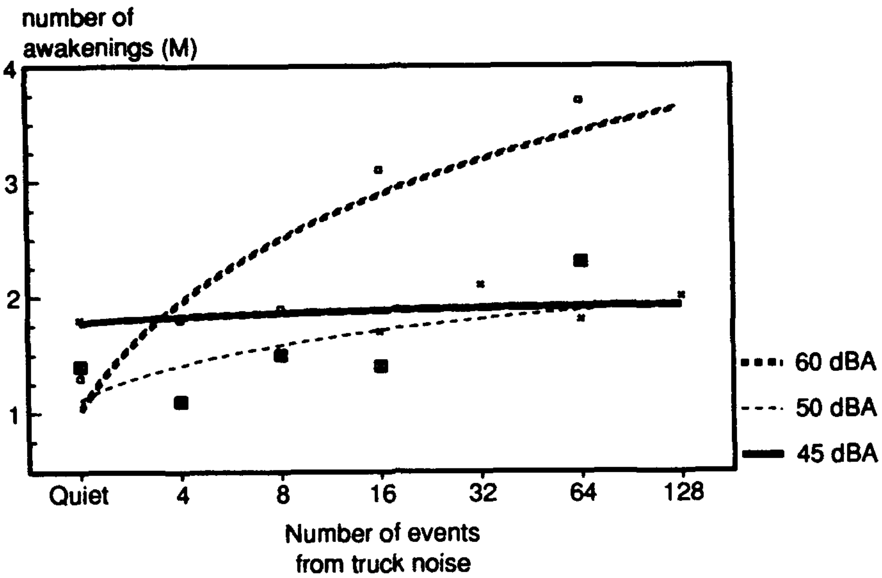

Figure 2 b. Number of ıwakenings at different L_{Amax} levels.

For awakening reactions the noise *level* is the most important factor of the noise exposure. As for the number only a slight increase is seen in the 50-curve, the 45-curve is a straight line and the 60- curve increases with number of noise events.

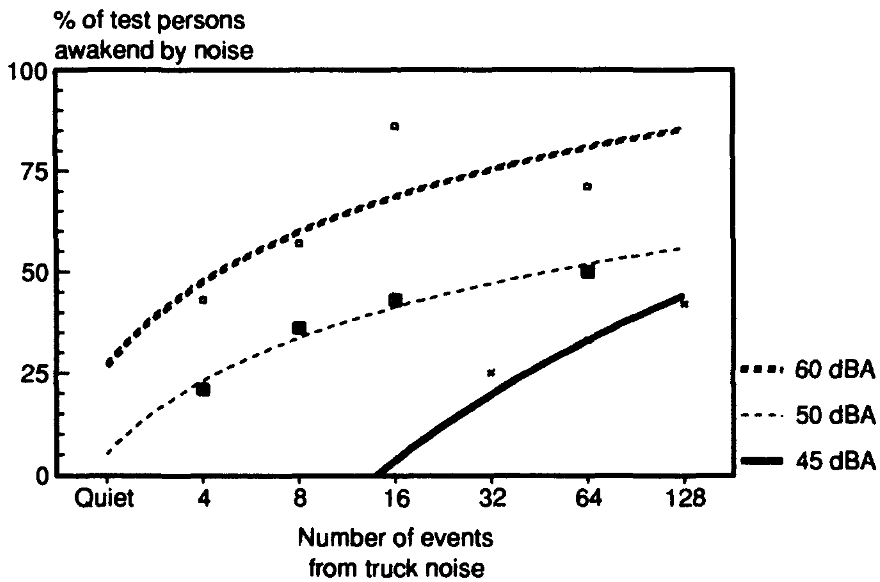

Figure 2 c. Percentage of test persons awakened by noise at different L_{Amax} levels.

Figure 2 c shows that the number of test persons who are awakened by noise increases with noise *level* as well as *number* of noise events.

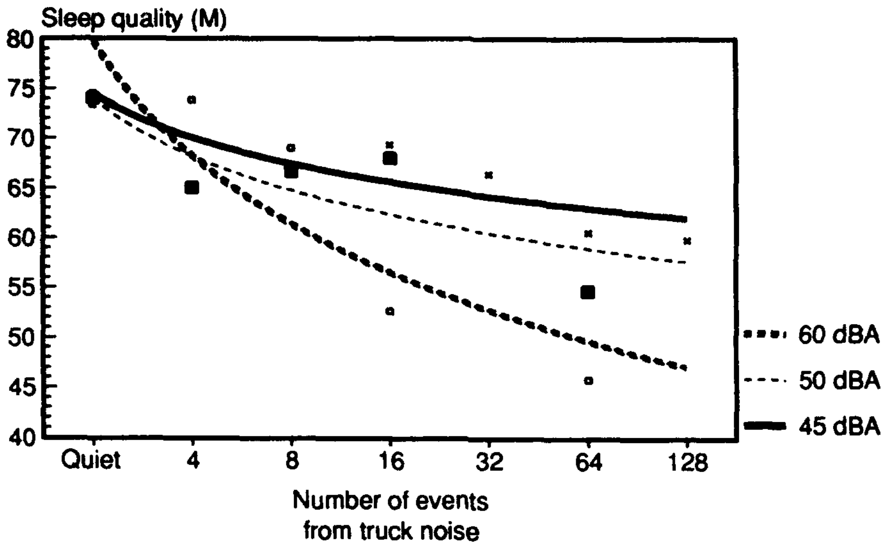

Figure 2 d. Subjective sleep quality at different L_{Amax} levels.

The noise *level* as well as the *number* of events is of importance for effects on subjective sleep quality.

The results showed a significant decrease in subjective sleep quality at 32 noise events per night. At 64 noise events (Leq=25.2), 50 % of the test persons experienced difficulties in falling asleep and, as compared with quiet nights, the time required to fall asleep was on average 12 minutes longer. The occurrence of body movements was significantly related to reported number of awakenings, and the number of body movements were three times higher during the noisy periods of the night as compared with the quiet periods, indicating acute noise effects. The results of a vigilance test indicate that noise during the night might prolong the time needed to solve the test. Finally, a tendency towards lower mood was seen after nights with noise exposure.

CONCLUSIONS

Among rather and very noise-sensitive subjects maximum noise levels of 45 dBA from road traffic cause a decrease in sleep quality at 32 noise events per night, increased difficulties to fall asleep at 64 noise events, acute arousal reactions as indicated by increased number of body movements in connection with noise events. The day after noise-exposed night-sleep there is an increase in tiredness. The combined results from earlier laboratory studies show a significant dose-response relationship between maximum noise levels and different subjective sleep quality parameters.

To protect people with a somewhat higher sensitivity to noise from disturbed sleep quality due to road traffic noise, maximum noise levels above 45 dBA should be avoided during night.

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MODELS TO DETERMINE CRITICAL LOADS FOR NOCTURNAL NOISE

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Abstract

The paper tries to present the state-of-the-art with respect to admissible limits which must not exceeded to avoid health impairments caused by noise-induced sleep disturbances. The very last papers which summarize the available literature and the last few field studies are discussed. Some suggestions are made for a directed continuation of this research.

1 Introduction

Complaints about noise-induced sleep disturbances are not most frequent. But, if they are experienced they are regarded as the most deleterious effects of noise, which impair health in the long run. Residents living in the vicinity of airports or in streets with high traffic load and suffering from noise during their leisure time and/or during the night claim vehemently for noise abatement and forced extensive research on this problem.

The studies executed within the last 3 decades revealed that both, the probability to be disturbed and the extent of the disturbances increase gradually with the sound pressure level. But these effects are not only determined by the physical parameters of noise such as frequencies, durations, and sound pressure levels. Instead, they are modified by many intervening non-acoustic variables. They vary with the experience a person has with a particular noise or its content of information, they are more frequent in aged persons, they are related to the personality of the people concerned, as well as with the actual situation.

2 Problems in the prevention of noise-induced sleep disturbances

These complex relationships result in a sigmoid-shaped function between noise and its effects which is additionally characterized by a large variation. Where on the one hand a few people are ever awakened even by the lowest sounds others are never disturbed - even by the loudest noise.

To prevent everybody from the effects of noise requires therefore either the cessation of any immission or the introduction of a large number of limits for special situations and special groups.

As both these suggestions are impossible to realize any other approach must simplify the problem and the implementations of preventive measures - such as upper limits - take in account that a certain amount of the population remains unprotected.

The elaboration and the implementation of upper limits require both valid acoustic parameters for the prediction of the effects and relevant criteria with respect to health.

3 Health effects

Though everybody is convinced that sleep disturbances impair health in the long run there is a vast uncertainty about the possible pathogenic significance of the various signs of sleep disturbances which are generally defined as measurable and/or subjectively experienced deviations from the usual or from the desired sleep behavior (Griefahn, 1985).

Some authors (mainly engineers) defend the opinion of people concerned that any measurable reaction impairs health disregarding the fact that reactions are essential signs of life. Neither vegetative alterations nor sleep stage changes or even awakenings are per se hazardous for health. The question is rather, at what extent and frequency - or at which dose - these reactions (may) affect well-being and health in the long run.

A pathogenic effect is theoretically well founded only for awakenings: if awakenings are recalled in the morning they determine subjective sleep quality and may then cause psychosomatic alterations and thereby contribute to the development of certain diseases. Noise-induced awakenings were adopted as most significant by the majority of the researchers and reviewers as well.

4 Prediction of noise effects

The A-weighted equivalent sound pressure level is most often used to assess human responses. But, as intermittent noise disturbes generally more than continuous noise, the mean acoustic energy cannot ever reliably predict the effects on man. According to a carefully executed study published by Eberhardt (1987) it is justified to characterize noises as continuous if the maximum levels of single events do not exceed the equivalent sound pressure level by more than 10 dBA. Intermittent noises are certainly better predicted by the maximum levels of the individual noise events and continuous noises rather by the equivalent sound pressure levels.

5 Admissible limits for noise during the night

Critical loads suggested so far consider almost exclusively
- noise from road traffic which concerns the majority of noise-exposed people and
- noise from air traffic which evokes - due to its high sound pressure levels - more awakenings than any other noise.

Due to the limited knowledge it is at present rather impossible to determine definite upper admissible limits. This implies that any suggestions are premature and require regular scrutinies and adjustments to the respective state-of-the-art. Tentative limits are of course not entirely satisfactory. Though they improve the situation for everybody they cannot prevent everybody from the deleterious effects of noise. Upper limits are merely compromises implying ever a remaining risk.

5.1 Admissible limits for road traffic noise

High density road traffic produces a more or less continuous noise. Though the sounds of the single noise events are still detectable, the equivalent sound pressure level is regarded as suitable for the assessment of sleep disturbances. Laboratory studies carried out by Eberhardt et al. (1987) revealed that the upper limit is undoubtedly below 45 dBA but that sleep is still undisturbed at L_{eq} = 36 dBA. Vallet and his coworkers (1983) observed 26 subjects sleeping in their own bedrooms. Based on the evaluation of the EEG and of the cardiac responses the authors calculated a critical load at 37 dBA. Griefahn (1985) executed a laboratory study with 36 subjects. The results were then related to the sleep behavior and to the noise exposure of the same subjects recorded at home. Thereafter, the upper limit for undisturbed sleep was determined at 40 dBA. In summary, the critical

loads suggested for vivid road traffic and probably other continuous noises vary within narrow limits between more than 36 dBA and less than 45 dBA.

5.2 Admissible limits for aircraft (and other intermittent) noise

Low density road traffic, railway traffic, and air traffic cause intermittent noises. The sound of the single events, passing vehicles or trains and flyovers exceed the background noise considerably and their effects on man are rather predicted by their respective maximum levels than by the equivalent sound pressure level estimated over the entire night.

5.2.1 Laboratory studies

The first systematic investigations on noise-induced sleep disturbances dealt with intermittent noise whereof aircraft noises including sonic booms were most often studied within the last 3 decades. Researchers were predominantly interested in the alterations which occur shortly after noise onset. These are awakenings as signalled by the subjects or assessed from the EEG, sleep stage changes, body movements or even vegetative alterations such as vasoconstrictions or heart rate accelerations.

Thiessen (1969) presented experimentally 7 truck noises during the entire night and registered occasional awakenings already at a maximum level of 45 dBA which he recommended as the upper limit. Based on the threshold for vegetative reactions, Jansen (1970) claimed that the maximum level must not exceed 55 dBA in more than 1% of the exposure time which is equivalent to 9 or 10 flyovers. A critical load of 68 dBA indoors was required by Lukas (1975) to prevent awakenings from aircraft noise.

These 3 reports though executed in the very beginning of this particular research represent nevertheless still the actual state. Nearly every report published since then suggests its own critical load which vary in a large range.

The great variations are widely and vehemently discussed among researchers, decision makers, and the people concerned. Conflicting interests and even the strangest demands are justified with reference to a 'suitable paper'. This situation is rather confusing and contributes certainly to the fact that many sponsors are no longer convinced about the value and the relevance of the research in this field. They even feel that the scientists are not able to solve these problems and they consequently refuse any further support.

5.2.2 Literature reviews

However, as most studies were carefully executed, it should be possible to draw valuable conclusions from all the investigations published until now, supposed that the respective conditions of the individual studies are adequately regarded. The present break should be used to analyse carefully the literature, to pool the data as far as possible and to generate hypotheses which allow directed and relevant studies - otherwise it is feared that this enforced pause is the very end of this research.

If the results from different studies are summarized, in particular if they are pooled for a recalculation some decisions are essential, at least for the criteria or signs of sleep disorders which are potentially hazardous for health in the long run, and the data must be weighed according to the methods, the specific conditions, the subjects, the evaluation, the results, etc.,

Hofmann and Heslenfeld (1992) analyzed the literature on noise and sleep since 1964. Using a meta-analytical approach they summarized the results of 58 publications where the methods of noise presentation and the measurements are well defined, where the subjects and the statistical procedures are adequately described and the results are pre-

sented quantitatively. They concluded that noise-induced awakenings become successively likely if a maximum level of 55 dBA is reached or exceeded. Sleep stage changes occur if noises reach at least 50 dBA. The authors reported additionally that aged people are more and children are less sensitive.

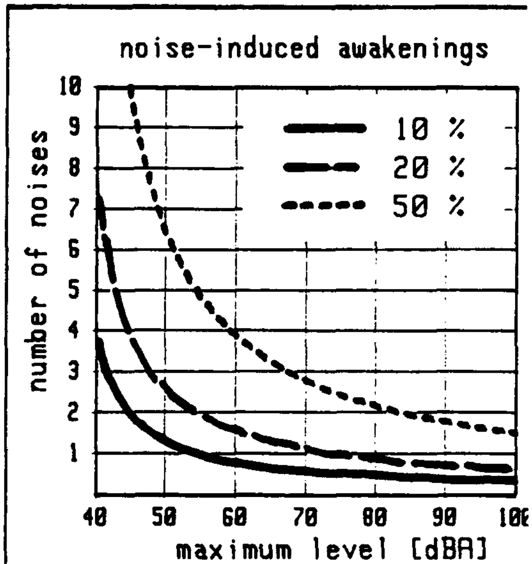
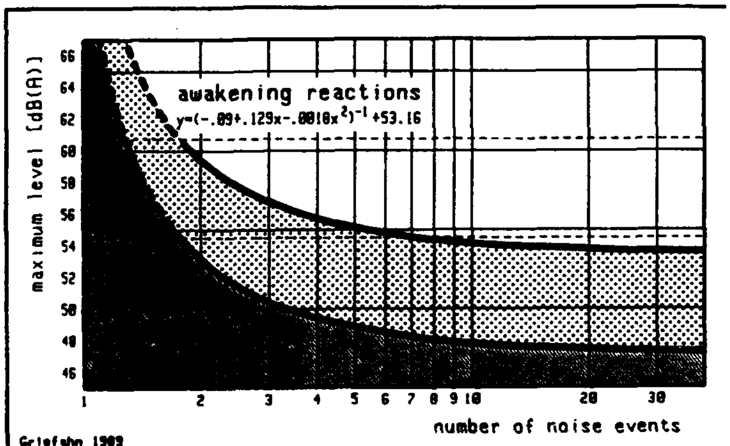


Figure 1

Griefahn (1992) performed a quantitative analysis wherefore she could not use more than 10 publications comparable in method and evaluation with altogether 94 subjects and 742 nights. A linear regression between the maximum levels and the probability of awakenings builds the basis for the calculation of various curves of equal risks. The curves in figure1 present the most simple approach. They presuppose a defined risk meaning a certain percentage of awakenings or of people disregarded and relate the number of noises to the respective maximum levels.

However, these curves are merely rough approaches to the problem in question. They disregard any other influence. As pointed out by Rylander et al. (1980) as well as by Hofmann and Heslenfeld (1992) noise-induced alterations are not only determined by the maximum level but also by the number of the individual noise events. The risk to be awakened by an individual noise decreases with the overall number of noises per night. Additionally, as observed in the laboratory, habituation takes place at least within the first few days and disturbances vary with age and with sleep depth (Griefahn, 1992; Ollerhead et al., 1992).



Limits for noise immission during the night
number of noises and maximum levels

Figure 2

These influences were regarded in figure 2. The respective curve of an equivalent admissi-

ble risk considers the most sensitive sleep stage, the increased responsiveness of aged people and a short habituation period of 6 nights. Supposed that the maximum level never exceeds 61 dBA, each point of the curve represents the same risk: a single awakening during the night of about 10% of the population. The respective risk for sleep stage changes is plotted beneath.

Comparing both the analyses of the literature presented by Hofmann & Heslenfeld (1992) and by Griefahn (1992) their suggestions are considerably narrow. Due to the large number of subjects involved the critical limit of 53 to 55 dBA seems to be well founded and reasonable. These admissible loads are also in accordance with Jansen (1970), who suggested a maximum level of 55 dBA due to the threshold of vegetative reactions and this was recently confirmed by Maschke (1992) who reported a decrease of sleep quality if he played back 64 flyover noises per night with maximum levels of 55 dBA.

5.2.3 Field studies

Nevertheless, these critical loads are vehemently questioned where 2 opposite opinions exist. Those who believe in the hazardous effects of any reaction assume that the limits are far too high and they argue that improper criteria were used. Others feel that the admissible loads are too low because they were deduced from laboratory experiments which again increase the responsiveness to external stimuli as compared to the usual situation at home.

Indeed, considering the conclusions of a review published by Pearsons et al. (1989) the limits in question seem to be extremely conservative. The authors analysed 53 papers, whereof 21 served for a recalculation. Among other variables such as age and sex, and the length of the observations, the authors regarded the type of the study and they found that noise-induced sleep disturbances are significantly less in the subjects' home than in the laboratory.

But, because of only a very few field studies Pearsons et al. could not determine definite upper loads. Instead, they presented a detailed list for problems to be solved in the nearest future and they imposed the criteria for further investigations. They required long-term studies in the field where the people concerned should be observed in their usual environment for at least 6 to 12 months.

Some of these recommendations were already realized in an extensive study executed by Ollerhead et al. (1992). The sleep of 400 subjects living in the vicinity of 4 airports were recorded by means of an actigram. Actimeters, somewhat bigger than a watch were tied to the wrist during 15 consecutive nights. During 4 sequential nights 48 subjects underwent simultaneous EEG monitoring to validate the actimetric records.

As the authors found a sufficient agreement between awakenings as diagnosed by the EEG and as indicated by the actigram they restricted their main considerations to the actigram and concluded - certainly with some reservations - that awakenings due to aircraft are most unlikely below a maximum level of 80 dBA outdoors.

Ollerhead's team observed also the sleep of 16 subjects after the single runway of one airport was closed. During a period of 16 consecutive nights the number of arousals did not significantly decrease as compared to the 15 nights recorded before the cessation of night traffic.

These results suit well to the reports of Pearsons et al. (1974) and Fidell & Jones (1975) who recorded and analyzed the sleep (EEG/EOG) of several residents and the subjective responses of 1400 habitants living in the close and more distant proximity of Los Angeles Airport before and after the cessation of a frequent nocturnal air traffic. After the cessation neither objective nor subjective alterations could be determined.

6 Conclusion

In summary, a great body of valuable studies were carried out within the last 3 decades and the knowledge in this particular field increased considerably. But the most important goal, the determination of an upper limit was not yet reached. The great discrepancies between the frequencies of arousals as recorded in the lab and in the field stress to the main problem. The divergent results are mainly related to the unusual situation in the lab which increases the responsiveness of man. Thus, these results overestimate the effects of noise. The same is presumably true for the field but to a lesser degree. It is absolutely impossible to observe natural sleep neither in the lab nor in the field because any recording introduces an experimental situation - and the situation at home becomes gradually less familiar the more parameters are recorded.

It is generally accepted that admissible limits must be determined in the field. But future investigations should be executed as long-term studies and they must include vulnerable persons. These are - among others - habitual poor sleepers and aged people, those who assess themselves as sensitive to noise, shiftworkers and those who usually work under stressful conditions as well as people who suffer from widespread chronic diseases such as hypertension.

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SOCIAL SURVEYS OF NIGHT-TIME EFFECTS OF AIRCRAFT NOISE

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Introduction

As part of a wider study of aircraft noise and sleep disturbance carried out on behalf of the UK Department of Transport (refs 1 & 2), which was mainly concerned with physical monitoring of people's sleep, a social survey has been made of 1636 residents near four UK airports. The principal aim was to provide a pool of subjects for the sleep monitoring and a means of sifting them. The survey was not intended to be a definitive study of perceived sleep disturbance, and the factors which influence it; this would have been much more elaborate and would have been designed and administered rather differently. However, the opportunity was also taken to collect data on general perceptions of aircraft noise and its effects, by day and, particularly, by night. This allowed comparisons to be made with earlier work, particularly the 1982 UK Aircraft Noise Index Study (ANIS) (ref 3) and social surveys of night noise nuisance carried out at two of the airports in 1979 and 1984 (refs 4 and 5).

The survey fieldwork, including pilot work to develop the questionnaire, was carried out by professional market research interviewers (PAS Ltd) in the summer of 1991. The questionnaire probed attitudes and reactions to aircraft and their noise. Some questions were aimed at specific night-time factors: sleeping habits, sleep quality assessments and the incidence and perceived causes of disturbance. Others were concerned with personal factors and availability which would affect participation in the sleep monitoring. Respondents were not told of the reasons for the study in advance. The average interview duration was 25 minutes.

General reponses

Very few respondents described themselves as bad sleepers and, according to their answers, they were roughly evenly divided between deep and light sleepers. Once in bed, between 30% and 45% of respondents reported difficulty getting to sleep, typically on two or three nights a week.

Most people reported being woken from sleep, but this occured 'regularly' in under 20% of cases. Typically, respondents said they were only awakened once per night. Most found it easy to get back to sleep although a significant minority (~25%) found it rather harder. Few were woken up at any particular times of the night although, of those who were, most mentioned midnight to 4am. Aircraft noise was given as a common reason for waking up. However, the main cause cited was being disturbed by partners or own children. Other reasons were noise from traffic and other outside sources and using the toilet. In total, slightly less than 50% of respondents felt refreshed or very refreshed after waking up and 25% felt tired or very tired.

Noise and annoyance

At least 200 residents were interviewed in each of eight 'common noise areas', sites where the outdoor aircraft noise exposure is relatively uniform. The average site noise exposures are expressed in dBA, Leq for daytime (0700-2300 local) or nighttime (2300-0700). It is usual to conduct social surveys of this kind during late summer/ early autumn and to relate the responses to the average summer day noise exposures which are fresh in the respondents' minds. However, the interviews in this study had to be completed betwen March and July and it was not possible to determine long-term average noise levels matched to the specific interview period, nor would it have been appropriate to do so in cases where the averaging periods covered months of winter and

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† This paper describes the views of the authors. It should not be construed as reflecting official CAA or Department of Transport policy

early spring. Thus, the values adopted, for comparative purposes, are those for the conventional summer period, mid-June to mid-September, of the preceding year, 1990 - on the assumption that responses to general questions about the effects of aircraft noise are likely to be most strongly influenced by experience of that period (being the busiest in the year).

A comparison with the ANIS results (Fig 1) shows that the percentages of respondents spontaneously mentioning aircraft noise as a reason for disliking the neighbourhood were in broad agreement. However, the two sites with the lowest aircraft Leq levels were near to a lightly used but rapidly expanding airport, and respondents there showed more awareness of aircraft noise than people experiencing similar daytime noise exposure levels at the other, more established airports.

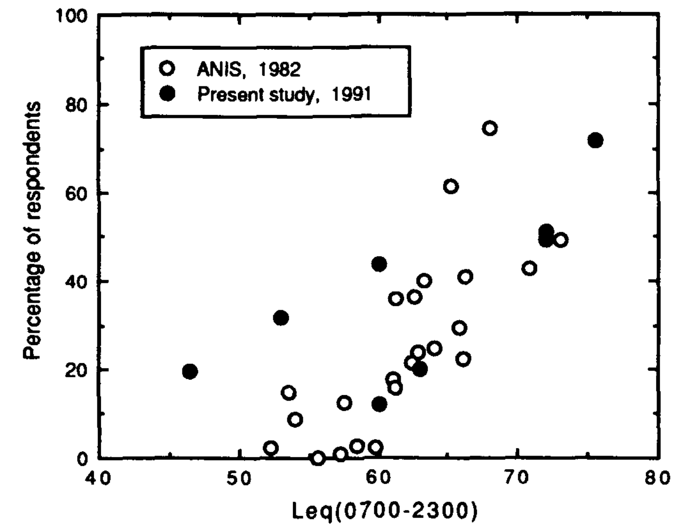

Figure 1 - Proportions of respondents citing aircraft noise as a reason for disliking their neighbourhood

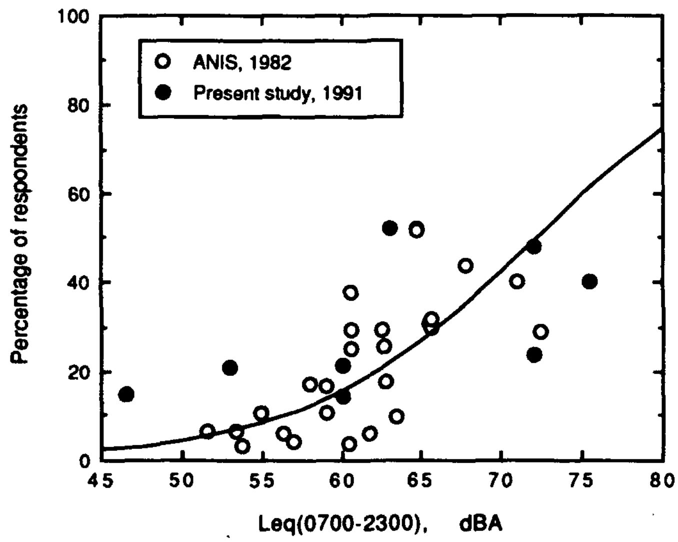

Figure 2 - Proportions of respondents who find aircraft noise 'very much' annoying (a logistic regression line is fitted to the ANIS data)

A similar effect emerged when comparing percentages of people 'very much annoyed' by aircraft noise (Fig 2).

Sleep disturbance

Comparisons with some of the the 1979 and 1984 CAA sleep survey results (references 4 and 5) are made in Figures 3 and 4. In each of these, the results from four surveys are plotted: (a) the present (1991) survey, 8 sites, 1636 respondents, (b) the 1979 interview survey (Ref 4), 8 sites, 964 respondents, (c) the 1979 postal survey (Ref 4), 22 sites, 3188 respondents, and (d) the 1984 postal survey, 5 sites, 1000 respondents (Ref 5).

Figure 3 shows the proportions of respondents (i) giving a positive answer to the question: *"Are you ever woken up once you are asleep?"* and (ii) mentioning aircraft noise in answer to the question *"What causes you to wake up?"*. Regression lines are fitted to the two data sets.

The results from the different studies exhibit similar trends, albeit with the scatter typical of social survey data. The percentages ever being awakened and giving aircraft noise as a reason for having difficulty getting to sleep indicate that, in relation to night noise exposure in Leq, general perceptions of nighttime aircraft noise effects changed little between 1979 and 1991.

However, although the 1979 and 1991 interview responses are similarly clustered (aircraft awakenings only), together they indicate lower levels of disturbance, on average, than the postal questionnaire data. Brooker (Ref 4) noted that such differences might be due to a bias caused by the respondents' knowledge of the objective of postal surveys; this can be hidden much more effectively in an interview survey.

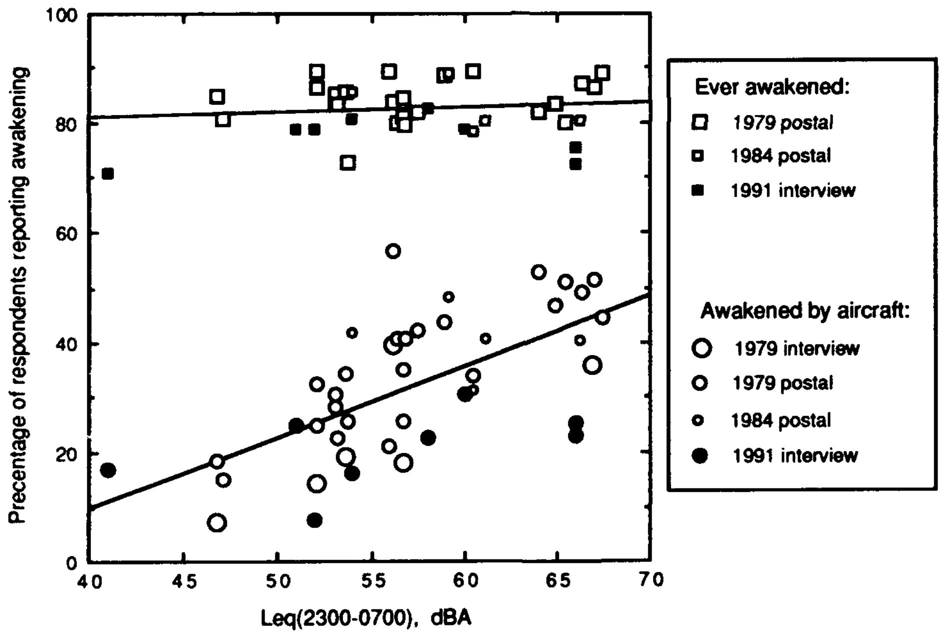

Figure 3 - Respondents reporting being awakened

Figure 4 relates to the questions (i) "do you ever have difficulty getting to sleep?" and (ii) "what makes it difficult to get to sleep?" Here, the differences are pronounced and the regression lines have been fitted separately to the interview data and postal data. Why these differences are so much greater than those in Figure 3 is the subject of continuing analysis.

Despite this question, the new data shown in Figures 3 and 4 supports the conclusion drawn from the earlier studies that, although total sleep disturbance (all causes) appears to have a minor dependence on aircraft noise exposure level, the proportion attributed to aircraft noise is strongly correlated with Leq.

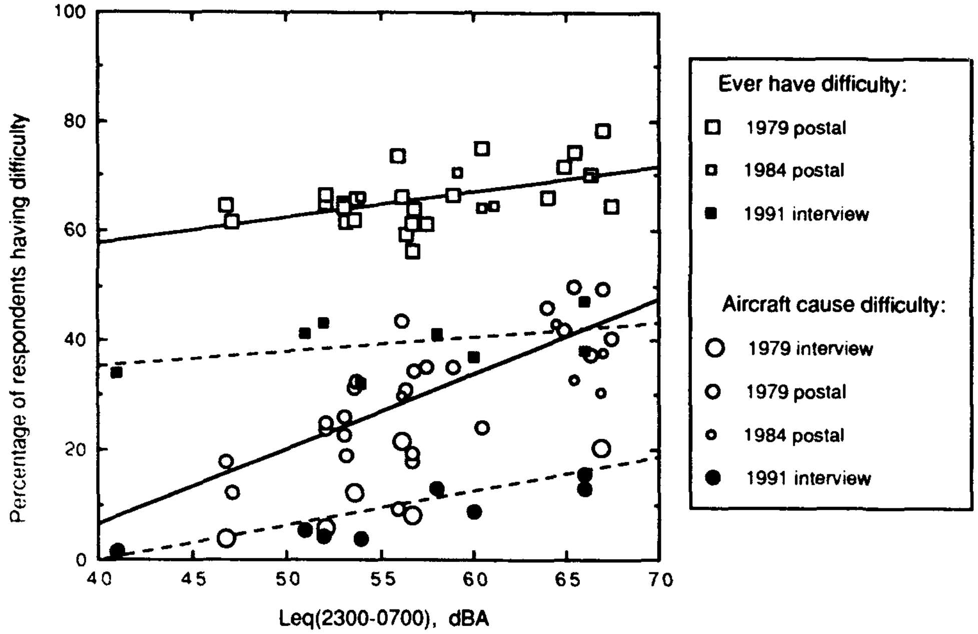

Figure 4 - Respondends reporting difficulty getting to sleep

Intervening non-acoustical factors

A multivariate analysis of the results which is still under way indicates how reported reactions to aircraft noise, both annoyance and sleep disturbance, are influenced by numerous intervening factors, notable amongst which are age, sex, marital status, and whether subjects describe themselves as light or deep sleepers. However, no clear relationships have emerged between aircraft noise exposure and reported incidence of sleep disturbances (all causes), whether known intervening factors (confounding effects) are controlled or not.

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EEG-BASED RESPONSES TO AIRCRAFT NOISE: PRELIMINARY RESULTS AND METHODOLOGICAL CONSIDERATIONS

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ABSTRACT

In order to assess the effect of aircraft noise on sleep in residents living near to the four main airports in the UK 46 paid volunteers were recorded for a total of 178 subject-nights in their homes while aircraft noise was recorded in the neighbourhood. An analysis technique was developed which allowed separation of "real" responses to aircraft noise events (ANE) from spontaneous arousals within sleep.

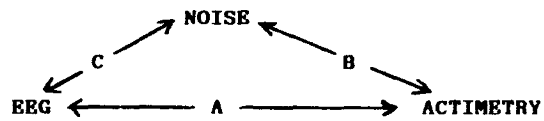
EEG recordings were made with a Medilog system which were visually checked and edited manually according to accepted criteria. During the recording nights, all out-door aircraft noises (>60 LMax dBA) in the close vicinity were recorded. In addition to sleep staging, detailed inspection of the sleepers EEG response to the ANE were visually investigated for arousals. Three categories of minor arousals were developed which were based on movement and EEG activation.

A total of 3,149 ANE were analyzed between 22.00 and 08.00 from sleeping subjects. Detailed inspection of the EEG data revealed that 14.4% of the ANE produced some type of response ie. either major or minor arousals while 10.3% was estimated to be due to background endogenous arousals. This could be interpreted as 4.1% of ANE or 1 aircraft noise in 24 caused some response in the EEG. Major arousals (shifts to W & MT) occurred much less frequently, with 4.17% of ANE and a background of 4.15%. This suggests that only 0.02% of ANE cause a major arousal in the EEG. The main type of responses were shifts to stage 1 and minor arousals (< 3 seconds). There was clear evidence of substantial biological variation in inherent arousals which affects the responsitivity of individuals. If there had been an endogenous arousal 2-5 mins before an ANE then the individual was twice as likely to respond to that ANE.

INTRODUCTION

This is a preliminary report on part of a large field-study to assess the effect of aircraft noise on sleep in residents living near to four major airports in the UK.

The main aim of the EEG recordings was to provide a database of traditional `gold standard` sleep recordings. This was used to validate the relatively new technique of actimetry which was the main method used in the project to assess sleep disturbance (reported elsewhere). That is, relationship A in the diagram below:



Once validated, the actimetry was used to provide an interpretation of B ie. the computed degree of sleep disturbance caused by aircraft noise. A further relationship (C) was explored with the data ie. the direct relationship between aircraft noise and EEG recordings. This made full use of the data and provided a valuable link with the majority of published literature in this field and additional support for the actimetry findings.

The analyses reported here involved a visual search for responses in the EEG, usually associated with sleep "disturbance", at the same time as aircraft noises were recorded in the neighbourhood ie. the evoked response in the EEG to the aircraft noise event (ANE).This type of analysis is relatively slow and labour-intensive. But allows finer criteria of 'sleep dis[illegible]nce' in the EEG data, than is possible to set using the ra[illegible]ogram which is based on 30 second epochs.

A recent review (Pearson et al, 1990) has shown wide divergence between laboratory and field results in terms of noise induced sleep disturbance. In addition, there has only been a limited amount of field work which has included objective measures such as EEG-based recordings. Previous work in this area has rarely controlled for inherent arousals within sleep. Because it is important to separate responses evoked by aircraft noise from ongoing background activity a technique was developed to control for endogenous arousals. Therefore, this study was carried out to further explore the effect of aircraft noise on residents asleep in their homes.

It would be impossible to present all aspects of the study and its results here, therefore we have concentrated on the methods employed and some of the main results.

METHOD

Sites and Recording sessions

A total of eight sites were chosen around four major airports (two at each of Heathrow, Gatwick, Manchester & Stansted) that would provide a range of aircraft movements and attendant noise exposures at night.

At each of the sites, six volunteers from the actimetry subject group (see below) were chosen to take part in the EEG recording sessions in two blocks of three subjects each. Each block of three subjects were recorded for four successive nights. The

start day of the recording sessions was varied systematically in order to avoid having the same nights of the week for all subjects.

The recordings were taken during the busy summer period, between March and October 1991.

Subject selection

At each site a social survey involving 200 subjects was conducted (Public Attitude Surveys Ltd.) and the data from this survey and subsequent interviews were used to select 50 subjects for actimetry (results to be reported elsewhere) and six of these for EEG recordings. Screening of potential EEG subjects ensured that they were:

a) Available on the specified recording dates
b) Did not wear a hearing aid
c) Were not taking sleeping pills
d) Were not taking medication that promotes sleep
e) Had good or very good hearing
f) Had good or very good health
g) Did not suffer from severe insomnia
h) Tended to go to bed before midnight and get up after 07.00

Besides the above screening, two further criteria were applied in selection of the EEG subset:

As equal numbers as possible of males and females, for the EEG subject group as a whole, were selected across three age bands; 20-34, 35-49 & 50-70.

The subjects taking part in the EEG recordings were paid £15 per night in addition to the £5 paid for actimetry recording. Subjects were not aware of the purpose of the study but were told that it was a Government sponsored project into sleep habits.

Recording procedures

Noise: The noise data was recorded by the CAA (UK) between 22.00 and 08.00. At each site, two or three microphones were positioned around the housing area under study. The microphones were linked to a central recording and processing system. ANEs could be identified because they were the only diffuse and overhead noise source which could trigger all the microphones at once, whereas more localized noise (eg. road traffic) would only be registered by one microphone.

All noise events, aircraft and others, were logged in terms of amplitude characteristics, dominant frequencies and exact time. The ANEs were subsequently synchronized with the hypnograms and actigrams. All associated aircraft movements were identified from airport logs according to landing or taking-off, routing and flight number.

It is well known that indoor noise levels could be between 10 and 35 dB less than the measures taken outside, depending on the structure and ventilation of the dwelling, the type of windows, and whether they were open or closed.

EEG: The recording and analysis of the EEG and associated measures (EOG, EMG & ECG) was based on the Medilog system (Oxford

Instruments Ltd). Eight channel recorders (type, 9200) were used to collect the data from each of three subjects per night. The clocks in these devices are accurate within +/- 5 seconds per 24-h and were checked every night.

Electrodes were attached by one of us (AW) in the subjects home in the evening (20.00-21.30) prior to the recording session. The subject retired and "got-up" as normal, indicating, via the event marker, the times of attempting-to-sleep and end-of-sleep. The Medilog recorders were left on continuous 'record' in the evening after the application of the electrodes. The recordings were terminated the next morning, by the subject, after they had arisen out of bed and removed the electrodes.

For all calibration settings and procedures the Medilog (Oxford Instruments Ltd.) manual was followed. Recording techniques were by accepted standard methods (Rechtschaffen & Kales, 1968).

It needs to be emphasized that the subjects were not instructed to follow any particular pattern of sleep and wakefulness. Rather, they were told to follow their habitual retiring and rising times during the recording period.

The subjects completed a sleep log 15 minutes after getting-up which included questions on sleep disturbing events and whether their bedroom windows were open (reported elsewhere).

Sleep stage scoring

Each subject-night tape was initially played back through the Medilog replay system (MS-9200-S) during which automatic computerized (7.2 software release) scoring took place.

Following the automatic scoring (Review 1) all the tapes (subject-night) were visually inspected to check on the scoring and this adjusted score (Review 2) was used in subsequent analysis. This production of Review 2 involved a screen-scoring check on the automatic score produced for Review 1. This 'screen-scoring' method has been applied successfully before (Hoelscher et al, 1989).

This sleep stage scoring was carried out blind in respect of aircraft noise events.

Sleep stage scoring reliability: In order to check on the sleep scoring reliability of the system 10 subject-night tapes were chosen at random and the sleep stage scoring system was repeated from the start, producing a Review 1 & 2. The reliability was then calculated as a percentage of agreement for all the staged epochs.

There was a variation of 3.75%, on average, between the original and checked automated method which arises due to hardware limitations associated with the extremely slow recording speed of the Medilog recorders. The manual intraindividual scoring reliability was 94%, similar to what is frequently reported for the traditional paper scoring method ie. 90-95%. The agreement between the automated and the manual scoring was 89% which again agrees well with the manufacturers claim of better than 85%.

The sensitivity of the scoring for movement time (MT) was increased by reducing the requirement for movement

arousals/artefacts from 50% to 30%. A total of 3,149 ANE were analyzed between 22.00 and 08.00 from sleeping subjects.

Estimation of background pseudo-responses

Every time a response to an ANE was noted it was necessary to determine whether; (a) this was a true response which had been evoked by the aircraft noise, or (b) if it was simply a reflection of a background pattern of inherent arousals (or pseudo-responses) generally experienced by that subject or, more specifically, being experienced by that subject at that time of night. Therefore, to help resolve this dilemma, every time a response to an ANE was noted two background readings were also taken :

(a) an immediate-background was investigated for pseudo-responses (arousals), 2-5 minutes before the ANE, and

(b) a general-background was investigated for pseudo-responses (arousals), 2-5 minutes before the nearest ANE to which there was no response (see below for details).

Figures 1 & 2, show the relationship of these measures to ANE.

ANE Response Analysis Criteria:

Criteria for analysis of responses to ANE:

1) The ANE start time was set at the time at which the external recorded noise level exceeded 60 dBA (Fig 1).

2) Subjects must have been asleep for a) two epochs before the response window & b) 1st 5 mins of the 10 mins before the ANE (>60 dBA). This allowed all types of sleep/wake activity to be included in the assessment of background state (see below).

3) To avoid summative interactions, there should not have been an ANE in the preceding 5 minutes that caused any response.

4) The start of the response window was 16 seconds before the noise-start-time (ie. rises above 60 dBA threshold). This allows for slight errors in noise timing over the site area and the possibility of hearing the aircraft before the 60 dBA threshold had been reached (see fig.1).

[Note: 16 seconds is the duration of a screen window on the Medilog Replay System.]

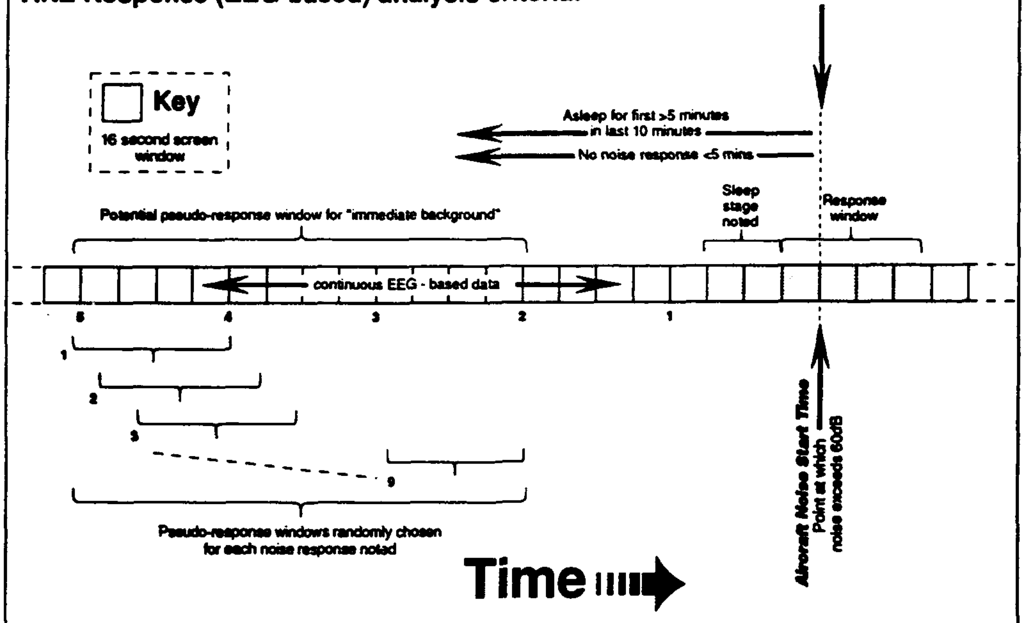
5) The end of the response window was 48 seconds (ie. 3*16 sec epochs) after the noise-start-time, as long as this contained the noise peak, if not, then it was extended to 16 seconds after the noise peak.

6) The sleep stage was checked with the hypnogram for the preceding 5 minutes and noted for 2 epochs (of 16 seconds each) before the ANE.

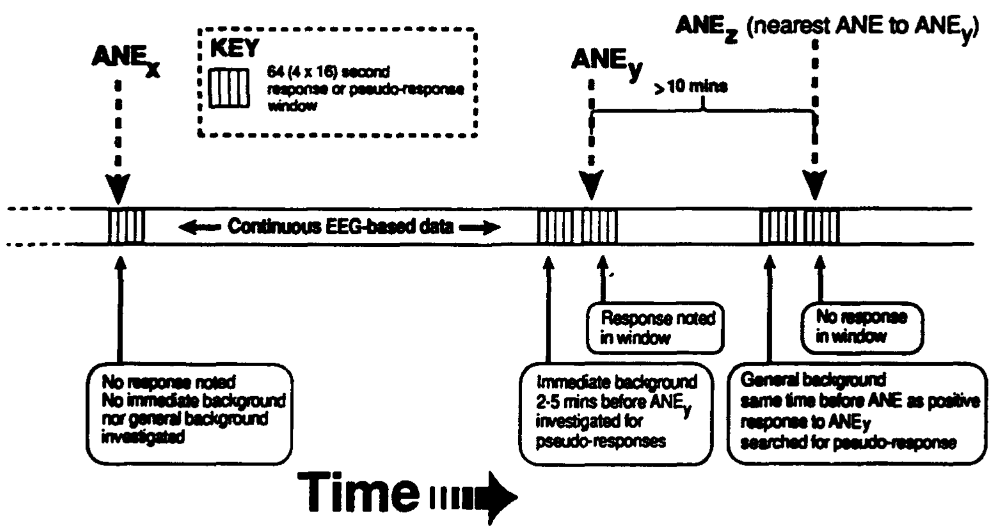
7) If a response to an aircraft noise was found, matched (equal number of epochs) non-aircraft noise windows were analysed for pseudo-responses and similarly scored.

8) Immediate-background: The temporal position of this pseudo-

Figure 1
ANE Response (EEG-based) analysis criteria:



Fgure 2
Immediate and General Background Analysis for Pseudo-responses



response/non-aircraft noise (immediate-background) window was randomly chosen (using random number tables) as 4 consecutive 16 second epochs between 2 and 5 minutes before the onset of the aircraft noise event.

9) General-background: In addition to a matched immediate-background, a general-background was also determined. This was achieved by investigating the nearest ANE (to the one which caused a response) to which there was no response. This general background window was set to be; more than 10 min after or more than 5 min before the ANE 'noise start time' to which there was a response (see Figure 2).

10) For each response noted, only the most severe response was logged eg. most shifts to stage I are associated with brief movement but only the shift to stage I was logged, no additional movement arousal score was recorded.

Classification of responses to aircraft noise events:

A) 'Major' arousal responses ie. shifts to Wake, Movement Time (>10 sec) & stage 1 and associated artefact scores, were already available in the hypnogram and trend plots. These were checked and noted. In addition, matched non-noise data (ie. pseudo-responses), both immediate and general-background, were collected, as indicated above. These responses which would be seen in the hypnogram are sometimes referred to as hypno-responses.

B) 'Minor' arousal responses eg. Movement time <10 sec, were noted and given a score; M1, M2 & M3, indicating the severity of the arousal:

M1) *Movement artefact in all channels or shifts to W'ness* >3secs<10secs, movement may be followed by EEG speeding &/or slow eye movements.

M2) Movement artefact in all channels or shifts to W'ness <3secs, movement may be followed by EEG speeding &/or slow eye movements etc.

M3) Abrupt increase in EMG, associated with 2+ K complexes within 3 seconds.

The categories M2 & M3 were combined after a reliability/validation exercise in which 100 ANE were rescored. This revealed that the most difficult differentiation was between M2 & M3 arousal categories. If these categories were combined then the rescore reliability was better than 90% while if they were separated the reliability was better than 80%.

RESULTS and DISCUSSION

EEG-based responses to ANE v general background pseudo-responses

The total number of EEG-based responses between 22.00-08.00, when 3,189 ANE were analysed was 458 ie. 14.4% (Table 1). The general-background pseudo-response rate was 10.3% indicating that the "true" response rate was 4.1%. In other words, one aircraft noise in 24, which is over 60 dBA outside the house, caused some form of response in the EEG.

Table 1 Summary of responses to ANE and pseudo-responses in the immediate and general background

	No. of ANE or background analyzed	No. of positive response identifications	%
Responses	3,189	458	14.4
General-background (pseudo-responses)	458	47	10.3
Immediate-background (pseudo-responses)	458	93	20.3

Although the noise levels at the subjects heads cannot be precisely determined, it should be noted that the windows were reported open on 58% of the subject-nights investigated.

On average, the time between the ANE to which there was a response and the corresponding ANE to which there was no response (and was used for the general-background determination) was 28 minutes (30 mins before and 25 mins after). It has long been established that the sleep process is affected by the time of night therefore this quasi-random approach for finding a comparable section of sleep to look for pseudo-responses, which gave an average value of about 1/2 hour, was considered acceptable.

This, general-background was found to have pseudo-responses for 47 of the 458 matched cases studied ie. on 10.3% of occasions (Table 1).

Type/severity of response

It needs to be emphasized that there were six different categories of response in the EEG with different degrees of severity, the most severe being shifts to wake or movement time. Table 2 shows the relative percentages of each type of EEG response to ANE from most to least severe ie. shifts to W, MT, stage 1, M1, to M2+M3 respectively. Table 2 shows that for shifts to wake or movement time, there was hardly any difference between the rates of responses to ANE compared with general-background arousals, 133 per 3,189 and 19 per 458 or 04.17% & 04.15% respectively. The difference between these, 0.02%, gives an indication of the proportion of ANE which cause shifts to W or MT that are not likely to be due to background.

Therefore, the EEG-based data indicates that being 'woken-up' (in terms of shifts to W or MT) by aircraft noise is a very rare event but this conclusion is partially limited by the sample size of the general-background data set.

The responses that account for the 4.1% "true" response rate (ie. 14.4-10.3) are seen from Table 2 which shows that shifts to stage 1 and the minor arousal M2+M3 are the two categories where there was a clear increase for ANE responses compared with the general-background.

Therefore, aircraft noise does cause detectable changes in the EEG-based data, but these are restricted mainly to a lightening in the depth of sleep ie. shift to stage 1 or brief (<3 sec) EEG arousals.

Responses to ANE v Immediate background pseudo-responses

The total number of all EEG-based responses, for the 22.00-08.00 window, when 3,189 ANE were analysed was 458 ie. 14.4% (Table 2).

For these responses, analysis of the "immediate-background" for the period just prior (2-5 mins) to the ANE showed that 93 of the 458 had some form of arousal before the ANE ie. 20.3% of the responses.

This, compares with a "general-background" which was found to have arousals for 47 of the 458 matched cases studied ie. on 10.3% of occasions.

The obvious conclusion to draw from this is; ANE that cause a response occur when the background EEG arousal rate is twice that which is found when an ANE does not cause a response.

Therefore, there seems to be a major biological variation in inherent arousals which, in part, appears to affect the responsitivity of the subject to external stimuli such as ANE.

As a consequence of this, it would not be appropriate to use the immediate-background rate of pseudo-responses for comparison with the responses to ANE because this represents a special case which eg. is temporally linked with the responses and, as demonstrated above, is more likely to indicate pseudo-responses.

Table 2 Response and pseudo-response rates (%) for ANE and backgrounds (22.00-08.00)

Type of arousal	Responses to ANE (%)	Pseudo-responses in background (%)	
		Immediate	General
No. of ANE investigated	3,189	458	458
Hypno-arousals			
W	1.69	1.09	1.09
MT	2.48	4.15	3.06
W+MT	4.17	5.24	4.15
Stage 1	2.98	1.53	1.53
W+M+St 1	7.15	6.77	5.68
Minor Arousals			
M1	3.54	4.37	3.28
M2+M3	3.67	9.17	1.31
M1+M2+M3	7.21	13.54	4.59
All	14.36	20.31	10.26

Comparison of Responses and Pseudo-responses

Comparison of the responses and the types of background (pseudo-responses) show some interesting differences:

The responses show a progressive increase in relative proportion of occurrence from major to minor arousals ie. from W, MT, stage 1, M1 to M2+M3.

The immediate-background to a response shows a higher proportion of the minor arousals (M2+M3) than is found with responses or general-background.

On the other hand, the general-background shows (Table 2) a high proportion of longer movements (MT and M1) than immediate-background.

Therefore, minor arousals M2+M3 seem to be the precursor for responses to ANE and these responses are more likely to be shifts to wake or stage 1.

Again, it should be noted that there is a limit to how far this line of analysis can proceed because of potential sampling error eg. with the six different categories of arousals determined from 458 observations of general-background only yielded 47 arousals ie. 10.3% which when divided between the 6 categories does not provide a large enough data set for confident statements to be made. This data can only be viewed as providing indications of trends.

CONCLUSION

ANE do cause detectable changes in the EEG of residents sleeping at home but these changes are mainly restricted to a lightening of the depth of sleep (shifts to stage 1) or brief arousals that rarely lead to awakening when all outside noises above 60 dBA are considered. Furthermore, a response was more likely if there had been an endogenous arousal within 5 minutes before the ANE.

There was clear evidence of biological variation in inherent arousals which affects the responsitivity of individuals. If there had been an endogenous arousal 2-5 mins before an ANE then the individual was twice as likely to respond to that ANE.

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ENVIRONMENTAL NOISE DURING SLEEP AND SYMPATHETIC AROUSAL ASSESSED BY URINARY CATECHOLAMINES

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ABSTRACT

Nine volunteer subjects slept in a laboratory for four nights. After one trial night the subjects were given one quiet night, one night of 50 recorded truck driveby noise 'events' and one night of 50 recorded aircraft flyovers at levels of 65 to 72 dBA_{max}. Arousal (alpha) responses during noise intervals (noise duration plus 20 sec.) and paired quiet intervals were studied from the noise nights. Overnight urinary catecholamines from the trial, noise and quiet nights were compared. On average, the noises increased the likelihood of an arousal response by a factor of five, but the proportions of arousals in the several sleep stages was unchanged by noise events. In spite of the apparent effects of the noise events on sleep there were no differences between 'noise' and 'quiet' nights in excretion of urinary adrenaline, noradrenaline or dopamine.

ABSTRAIT

Neuf sujets s'étaient portés volontaires pour dormir quatre nuits dans un laboratoire. Aprés une nuit à l'essai, les sujets ont passé une nuit au calme, une nuit ou on leur a passé une succession de cinquante passages de camions et une autre de cinquante avions a des niveaux de 65 decibel à 72 dBA_{max}. Des réactions (alpha) de réveil durant les intervalles de bruit (plus de vingt secondes de durée de bruit) et des intervalles parallèles de repos ont été étudiés pendant les nuits bruyantes. Les catécholamines urinaires des essais durant les nuits calmes et bruyantes ont éte comparées. En moyenne, les chances de réveil augmentaient au coefficient cinq par les bruits, mais les proportions de réveil durant les différentes étapes de sommeil, sont restées inchangées par les bruits courants. Malgré les effets apparents causés par les bruits courants sur le sommeil, il n'y avait pas de différence entre "nuits bruyantes ou calmes" dans la sécrétion d'adrénaline urinaire, noradrénaline ou de dopamine.

INTRODUCTION

Sleep is accompanied by reduced heart rate and blood pressure [1,2], reduced frequency and grade of ventricular premature beats[3], and lengthening of the Q-T interval of the electrocardiograph[4,5]. These sleep-related changes have been attributed to sympathetic withdrawal and/or increase in parasympathetic tone[3,4,5]. Concentrations of circulating catecholamines normally are at their lowest during sleeping hours[6].

There is also a circadian variation in the onset of acute myocardial infarction[7]. This occurs most frequently between 6 and 11 a.m., i.e. at the time of day when sleepiness is at its lowest, suggesting that sleep has a cardioprotective effect for many patients.

Noradrenaline is the main sympathetic neurotransmitter in the heart. Much of it is removed from circulation by re-uptake by the sympathetic nerves, but spillover into the blood is proportional to cardiac sympathetic nervous firing rate. Adrenaline is primarily an adrenal medullary hormone which affects heart function. Noradrenaline release in the heart and the secretion rate of adrenaline are susceptible to mental challenge, even by relatively mild stressors[8]. The sources and function of

dopamine are as yet unclear. All catecholamines released in the body but not subject to re-uptake are ultimately excreted in the urine in their native form or as metabolites, which occur in the same proportions as the native forms. Total catecholamine excretion in the urine is therefore an accurate indication of the average level of sympathetic nervous tone overnight.

It is known that very high values of adrenaline and noradrenaline can have harmful effects on the heart, including minute haemorraghes, arrhythmias and coronary spasm. However, little or nothing is known of the effects of chronic elevations of catecholamines during states of rest, such as sleep, on the heart. If sleep is compromised by environmental factors such as noise, and if this is accompanied by an increase in catecholamine level, then the risk of harmful sequelae may be increased.

We carried out a study of the effect of transportation noise during sleep on arousals and sleep stage change and the overnight excretion of urinary catecholamines.

SUBJECTS AND METHOD

Subjects. The subjects were nine outpatients who presented to the Cardiology Department of the Royal North Shore Hospital, Sydney, with a history of cardiac arrhythmia. One subject was aged 26. The ages of the other eight subjects ranged from 46 to 75 years with a mean of 61 years.

Each subject slept in a laboratory for four non-consecutive nights. The first night was used to familiarise them with the test environment and procedure. The second, third and fourth nights consisted of one 'quiet', and two 'noise' nights (with truck and aircraft noise respectively) in counterbalanced order between subjects.

Noise Type and Level. Stereophonic recordings of truck passbys and aircraft flovers were replayed into the room where the subject was sleeping. The noises were monitored using a microphone, sound level meter, frequency analyzer, and level recorder. By these means the A-weighted levels and the time histories of all noises presented to each subject were traced on the polygraph chart simultaneously with the physiological data.

Noise Exposure. 50 aircraft or truck noise 'events' were scheduled for each 'noise' night. The intervals between noise presentations were randomised, and ranged from three to twenty minutes. The maximum levels of noise were varied between 65 and 72 dBA_{max}. Average durations were 24 seconds for aircraft noise and 17.8 seconds for traffic noise.

Polygraphic Monitoring of Sleep. Vertex (C3-A2) EEG, right and left EOG, submental EMG and the time course and level of the noise were recorded continuously on an eight channel polygraph chart throughout the night. Sleep stage and arousal responses to the noises were visually scored as follows. A point was marked on the chart two seconds before onset of each noise. A second point was marked two seconds after offset of the noise. A third point was marked on the chart corresponding to 20 seconds after the second (noise offset) mark. The sleep polygraph in the interval between the first and third marks was then examined for: (i) sleep stage at commencement of the interval; (ii) appearance of alpha frequency (8-12 Hz) in the EEG *after* commencement of the interval (called an alpha response); (iii) alpha onset latency, in seconds after commencement of the interval; (iv) number of sleep stage changes during the interval.

Sleep stage was assessed visually using standard methods[9] but applied in 10-second epochs to enable more precise definition of sleep stage at onset of noise and paired quiet intervals, and a more detailed account of changes in sleep stage than would be permitted by 20-second, 30-second or one-minute epochs.

To study the effects of noise and distinguish them from spontaneous arousals and sleep stage changes the same scoring procedure was carried out on an equal number of paired quiet intervals. each commencing two minutes before noise onset. The duration of each quiet interval was the same as its corresponding noise interval.

Measurement of Urinary Catecholamines. Subjects were required to void before retiring. All urine subsequently passed was saved, including a final collection in the morning. Noradrenaline, adrenaline, and dopamine were extracted with alumina and cation exchange columns, and then separated by high pressure liquid chromatography (HPLC), using a C18 column and electrochemical detection[1].

RESULTS

Arousal Response. An arousal response was defined as the appearance of alpha frequency in the vertex EEG after the onset of a noise or paired quiet interval, and identified for both 'noise' nights for each subject. Sleep stage at onset of each interval was also recorded. Table 1 gives the proportions of noise and quiet intervals containing alpha responses, for each sleep stage at interval onset. These proportions are from data pooled across all subjects and the two noise nights. It will be seen that 53% of the noise intervals where the subject was asleep at interval onset showed an arousal response, whereas only 11% of the quiet intervals did so.

A generalised linear model was fitted to the data. It was found that both sleep stage and noise were related to the probability of an arousal response ($p < .05$), but that there was no significant interaction between the two factors. The probability of an alpha response decreased from stages 1 to 4. There was no significant difference between the probabilities of an alpha response in stages 3 and 4 although this may have been due to the limited amount of data for stage 4 sleep. The probability of an arousal response to noise in REM sleep was similar to that in stage 2 sleep.

Table 1. Arousal Responses per Interval

Intervals	Sleep Stage at Interval Onset					
	Stage 1	Stage 2	Stage 3	Stage 4	REM	All Sleep
Noise	0.60	0.58	0.33	0.28	0.52	0.53
Quiet	0.16	0.09	0.07	0.00	0.10	0.11

Clearly noise facilitates an arousal (alpha) response, less effectively during slow wave sleep than when the subject is in other sleep stages. However there is also less likelihood that an alpha response will appear 'spontaneously' in quiet intervals commencing in stages 3 and 4 than quiet intervals commencing in stages 1, 2 or REM. The ratios of the probabilities of alpha responses appearing in noise and quiet are similar regardless of sleep stage at interval onset.

Alpha onset latency and number of sleep stage changes per interval were subjected to similar analyses as dependent variables. It was found that both were related to noise and sleep stage at interval onset. As might have been expected, noise was associated with a shorter alpha onset latency. However this was not true of those noise intervals in which the subject was in stage 4 at the start of the interval. In this case the alpha onset latencies were not significantly different from those occurring 'spontaneously' i.e.during quiet intervals.

Catecholamines. The means of the assays of noradrenaline, adrenaline, dopamine for the first ('trial') night and for each noise/quiet night are plotted in Figure 1. A two-factor analysis of variance, with noise/quiet nights as one factor and catecholamine the other, was carried out. The 'noise' effect was not significant ($p>.05$) and there was no significant interaction between noise treatment and catecholamine type.

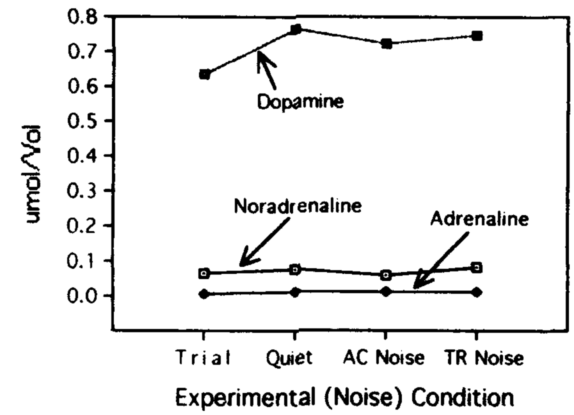

Figure 1. Overnight urinary catecholamines

DISCUSSION

Arousal Response. As Williams[11] pointed out, early definitions of sleep stages[12] included a behavioural component related to a continuum of the 'arousability' or 'depth' of sleep as well as to characteristics of the EMG, EOG and EEG. Williams also cited research which appeared to show that differences between sleep stages in arousability only apply to 'behavioural awakening' in which the subjects are instructed to press a button or otherwise indicate that they are awake. Such differences in arousability, he said, do not obtain when EEG-based arousal responses are studied. Williams concluded that the apparently higher thresholds for behavioural awakening in stage 4 sleep are due to processes involved in the "organisation and control of motor responses"[11], and that the existence of a continuum of depth of sleep was questionable.

As shown in Table 1 of the present paper, 53% of all noise intervals included an arousal (alpha frequency) response. In comparison, 11% of quiet intervals showed arousal responses, demonstrating that while spontaneous arousals are indeed characteristic of the sleep of the elderly[13], environmental noise at levels of 65 to 72 dBA increased the frequency of these arousals by about five times.

From Table 1 it can also be seen that the likelihood of an arousal response in both noise and quiet depends on sleep stage, with the frequency of alpha responses progressively decreasing from stage 1 to stage 4. This may be related to the trend toward greater energy in the low frequencies in the spectral composition of the vertex EEG. If so, REM sleep is again 'paradoxical' in that while its EEG is closest to the awake EEG the likelihood of an arousal response is very similar to that of stage 2 sleep. Table 1 also indicates that the effect of noise is greater for stage 1 than stage 2, 2 than 3, and 3 than 4. However noise increases the likelihood of an arousal by the same ratio regardless of sleep stage. Put differently, whatever the propensity to arousal at any time during sleep may be, the effect of the transportation noise was always to increase that propensity by five times.

The present results would appear to show that whether or not one considers that there is a dimension of depth of sleep associated with sleep stage would depend on the way depth of sleep is defined. There are at least four such definitions. The first might be in terms of the lowest noise level at which the number or likelihood of arousal responses is increased. The second could refer to the number or probability of spontaneous arousals during any given time period in each sleep stage. The

third might depend on the relation between frequency of arousal responses to noise and sleep stage at noise onset. The fourth could compare the ratio of the frequency of noise induced arousals to spontaneous arousals in each sleep stage.

The present study cannot throw any light on the threshold of arousability and stage of sleep, since the level of the noise was not systematically varied. However from our data from quiet intervals it would appear that there is a basic propensity to arousal which varies systematically with sleep stage as shown by the polygraph. Depth of sleep would appear to be a reasonable way to describe this propensity. Noise operates on this basic propensity to arousal and sleep responds proportionately to its propensity to arousal at that time. However this does mean that noise results in a much greater differences between the *number* of arousals occurring in intervals commencing in different sleep stages.

Catecholamines. Figure 1 indicates that the overnight excretion of adrenaline, noradrenaline and dopamine is not affected by up to 50 noise events during the night, even though 53% of these events are shown to have elicited arousal responses.

From the point of view of environmental noise control these results are reassuring. However they should be treated with caution. Overnight urinary catecholamines and their metabolites faithfully represent the total catecholamines released and not taken up by sympathetic nerve endings. As a total measure they may be more reliable than measures of plasma catecholamines, because they reflect activity over the whole night instead of a small part of it. However they cannot reflect short term increases in the peak levels of circulating catecholamines which could be associated with short term events such as mental challenge and noise-induced arousals from sleep.

A second limitation of assays of overnight urinary catecholamines for estimating potential effects on the heart is that large differences in noradrenaline release have been demonstrated between different regions and organs of the body in response to mental challenge. For example, in studies of response to mental challenge in awake people, norepinephrine spillover from the heart increased by a factor of three, while simultaneous increases of noradrenaline in skeletal muscle in the forearm were negligible[8]. The same differences between release of noradrenaline and other catecholamines could apply between the heart and other bodily regions in response to noise-induced arousal from sleep. The result could be an underestimate of effects on particular organs such as the heart.

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SUMMARY OF TEAM 5: EFFECTS OF NOISE ON SLEEP

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1. PRIORITIES OF RECENT AND FUTURE RESEARCH.

From what has been reported during this conference and from publications from the last 5-year period as well as previous publications, we conclude that considerable new knowledge on noise and sleep disturbance effects has been achieved. It is also encouraging that it is now gnerally accepted that laboratory studies and field studies are both needed to understand the effects of noise on sleep.
As already stated in the plenary session (4) five research topics are considered as most important during the last 10 years.
These topics concern:

- predictive indicators of sleep disturbances for presumed health effects
- critical groups and critical situations
- most sensitive period of the night
- significant components of noise and upper noise limits
- evaluation of long term effects of countermeasures

Research is still needed in these areas and during the discussions here, we added one more important issue -

- effects of noise on daily activities.

We strongly suggested that we should increase the possibilities to compare the results from different sleep studies (e.g. by exchanging questionnaires for evaluation of sleep quality) and to encourage collaboration between the sleep team and other teams, especially on community response (team 6) and performance (team 4).

2. CONCLUSIONS FROM PREVIOUS STUDIES AND STUDIES COMPLETED SINCE 1988.

Concerning the 6 topics just specified the results of some studies executed since 1988 allow to draw some conclusions an to formulate well founded hypotheses for future research.

2.1. Predictive indicators of sleep disturbances for presumed health effects.

The determination of long term health effects from noise-disturbed sleep is still unsolved except for the effects according to the WHO definition of health. We know that sleep quality as assessed in the morning (which is related to difficulties to fall asleep and to the number of awakenings) is reduced by noise (Öhrström 5 and 6, Hume et al 7). Tiredness during the day is increased (Öhrström 6) and this has, sometimes been shown to have a pronounced effect on performance (Jürriens et al 8) or is at least connected to a feeling of discomfort.
A field survey in six city areas (Öhrström 6) showed long term effects of noise-disturbed sleep in terms of lower sleep quality and lower psycho-social well-being among people having bedroom windows facing the street as compared to those having bedroom windows facing the courtyard.

A new and interesting hypothesis, that has been discussed during this conference is the effect of noise-disturbed sleep on the secretion of catecholamines (Carter et al 9, Maschke et al 10) and on the immune system (Altena et al 11). However, these effects have not yet been proven.

During the conference preliminary results from an extensive field study on the effects of aircraft noise on sleep were presented (Horne et al 12, Diamond et al 13, Ollerhead et al 14 and 15, Van et al 16, Hume et al 17). The study involved 8 areas at different distances from four airports and the sleep behavior was assessed by questionnaires (200 x 8 subjects), by actimetry (50 x 8 subjects) and by EEG (6 x 8 subjects). Methodological issues (e.g the relevance of actimetry for measuring awakenings induced by aircraft noise) and the interpretation of the results were discussed as well as the significance of individual noise exposure levels.

2.2. Critical groups and critical situations.

- *Noise-sensitive groups* react at 5 dB lower noise levels than the average population. Among the average population there is a considerable increase of awakenings above 53-55 L_{Amax}.
- *Ill people* - one study (Carter et al 9) shows that people with cardiovascular diseases are sensitive to arousal effects from noise. This is however not yet quantified.

- *Elderly people* are more sensitive to noise since their sleep is more shallow.
- *Critical situations* are related to unfamiliar noise, day-time sleep (which concerns shiftworkers (Nicolas et al 18), small children (Koszarny 19), high air temperature), early morning hours and noise during time for falling asleep.

2.3. Characteristics of noise exposure.

- *Intermittent noise* disturbs more than continuous noise. When an intermittent noise starts to be experienced as continuous is still not clarified.
- *Large difference between background and maximum noise level* increases the possibility to perceive and to react to the noise.
- *Noise in combination with vibrations* increases the risk for sleep disturbances.

During this conference a paper was presented on the effects on sleep of noise from different sources: train, aircraft and trucks (Hofman et al 20). The preliminary results showed no differences between the noise sources concerning the overall effects on sleep. However, train noise of 65 dBA tended to induce more acute arousal effects than truck noise. These results are not in agreement with earlier studies (Vernet 1979) who found that train noise caused less sleep disturbances than road traffic noise. The analysis of the results from this laboratory study was still not finished and the results on subjective sleep quality remain to be done.

2.4. Upper limits.

A model has been suggested by Griefahn (22 and 23) to protect from *awakenings* and *minor sleep alterations*. For intermittent noise the level should not exceed 53 L_{Amax} and 47 L_{Amax} respectively.
Kozarny (19) has suggested that Leq-levels outside nurs v schools should not exceed 60 L_{Amax} to protect the sleep of small children.
According to the WHO-recommendations (24) the inside noise level should not exceed 45 L_{Amax} and the Leq-level should not exceed 30 dBA. These recommendations by WHO are well in accordance with findings in laboratory and field studies reported on this conference (5, 6, 22 and 23).

2.5. Evaluation of countermeasures (barriers, double-glazing, traffic regulations)

There are very few studies on this topic. One study published since the last ICBEN-conference (Öhrström et al 25) indicates that a reduction of number of heavy vehicles during the night did not have a significant effect on sleep quality.

2.6. Daily activities.

So far no effects in terms of physiological health disorders due to noise-disturbed sleep has been proved. If these effects exist, they will be very difficult to prove due to interactions between different environmental and individual factors. The search for such effects has to continue but new studies are needed on after-effects for example on daily activities and napping during daytime and counter measures such as the use of sleeping pills and earplugs. For this purpose also new and more sensitive performance test should be developed.

3. SUMMARY

In summary, more research effort is needed in all the six topics mentioned above. To solve these questions both laboratory and field studies are needed. We believe, however that special attention should be focussed on evaluation of long term health effects and of long term effects of countermeasures against noise involving different groups of the population.

This kind of research is very time-consuming and thus collaboration between different research teams and agreement on (at least) some common methods would be very helpful. We believe that a workshop should be arranged not only for our sleep team but also for those who are working in other fields, especially on community reactions and performance. This would be very useful for discussions and collaboration in future studies.

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Les effets du bruit sur le sommeil
Résumé de l'équipe 5
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1- Priorités de la recherche récente : future

De ce qui a été rapporté pendant cette conférence ainsi que dans les publications des 5 dernières années aussi bien que les publications antérieures, nous concluons que de nouvelles connaissances sur le bruit et ses effets sur le sommeil ont été découvertes.
C'est encourageant de savoir qu'il est maintenant généralement accepté que les études en laboratoire et sur le terrain sont toutes deux utiles pour comprendre les effets du bruit sur le sommeil.

Comme il a été déjà exposé en séance plénière (4), 5 thèmes de recherche sont considérés comme les plus importants des dix dernières années.

Les thèmes concernent :
- Les indicateurs de prévision sur les troubles du sommeil pour présumer des effets sur la santé.
- Les groupes et les situations à risque
- La période la plus sensible dans la nuit
- Les composants signifiants du bruit et ses limites supérieures
- L'évaluation des effets à long terme des mesures antibruit.

La recherche est déjà utilisée dans ces domaines et pendant la discussion nous avons ajouté encore un résultat important :
- Les effets du bruit sur les activités diurnes.

Nous suggérons avec force que nous devons augmenter les possibilités de comparer les résultats des différentes études sur le sommeil (par exemple, en échangeant des questionnaires d'évaluation sur la qualité du sommeil) et d'encourager les collaborations entre l'équipe du Sommeil et les autres équipes spécialement celles de la Réponse sociale (équipe 6) et de la Performance (équipe 4).

2- Conclusion des études antérieures et des études complétées depuis 1988

Concernant les 6 thèmes, les résultats de quelques études réalisées depuis 1988 permettent de tirer quelques conclusions et de formuler des hypothèses pour des recherches futures.

2-1 Les indicateurs prévisionnels sur les troubles du sommeil pour présumer les effets sur la santé.

La détermination des effets à long terme sur la santé dus au sommeil troublé par le bruit est pratiquement insoluble sauf pour les effets se rapportant à la définition de la santé par l'OMS. Nous savons que la qualité du sommeil comme il a été établi ce matin (présentation des diffcultés d'endormissement et le nombre de réveils) est réduite par le bruit (Öhrström 5 et 6, Hume et al 7). La fatigue durant la journée est accrue (Öhrström 6) et ceci a montré quelquefois qu'il y a un effet prononcé sur les performances (Jürriens et al 8) ou, en définitive, est relié à une sensation d'inconfort.

Un domaine d'études dans 6 villes montrait les effets à long terme du sommeil troublé par le bruit en terme de qualité du sommeil profond et de bien-être des gens qui ont des chambres face à la rue comparés à ceux qui ont des chambres donnant sur la campagne. Une nouvelle hypopthèse intéressante qui a été discutée pendant la conférence est l'effet du sommeil troublé par le bruit sur la sécrétion de catécholamines (Carter et al 9, Maschke et al 10) et sur le système immunitaire (Altena et al 11). Toutefois, ces effets ne sont pas encore prouvés.

Durant la conférence, les résultats préliminaires d'un large domaine d'études sur les effets du bruit des avions sur le sommeil ont été présentés (Horne et al 12, Diamond et al 13, Ollerhead et al 14 et 15, Van et al 16, Hume et al 17). L'étude proposait 8 zones à des distances différentes de 4 aéroports et les dormeurs ont été interrogés par questionnaires (200 x 8 sujets), par actimétrie (50 x 8) et par EEG (6 x 8). Les données méthodologiques (par exemple, l'utilisation de l'actimétrie pour compter les réveils entraînés par le bruit des avions) et l'interprétation des résultats ont été discutés autant que la signification des niveaux individuels d'exposition au bruit.

2-2 Les groupes et situations à risque

-Les groupes sensibles au bruit réagissent à des niveaux inférieurs de 5 dB que la population moyenne. Parmi la population moyenne, il y a une augmentation considérable du nombre des réveils au-dessus de 53-55 LA max.

-Les personnes malades - Une étude (Carter et al 9) montre que les personnes qui ont des problèmes cardio-vasculaires sont sensibles aux effets d'éveil du bruit. Ceci n'est toutefois pas encore quantifié.

- Les personnes âgées sont plus sensibles au bruit dès que leur sommeil devient plus superficiel.

- Les situations à risque sont reliées au bruit non familiers, au sommeil diurne (qui concerne les travailleurs postés, les jeunes enfants, la température de l'air élevée), les premières heures du matin et le bruit pendant la période d'endormissement

2-3 Les caractéristiques de l'exposition au bruit

- Le bruit intermittent gène plus que la bruit continu. Le moment où le bruit intermittent devient continu n'est pas encore établi.

- La grande différence entre le bruit de fond et le niveau maximum accroît la possibilité de percevoir et de réagir au bruit.

- Le bruit combiné avec les vibrations augmente le risque de troubles du sommeil.

Durant cette conférence, un papier a présenté les effets sur le sommeil de bruits provenant de plusieurs sources : le train, l'avion et les camions (Hofman et al 20). Les résultats préliminaires montrent qu'il n'y a pas de différence entre les sources de bruit concernant l'effet global sur le sommeil. Toutefois, le bruit d'un train à 65 dB tend à induire plus de réveils que le bruit des camions. Ces résultats ne sont pas en accord avec les recherches plus anciennes (Vernet 1979) qui trouvaient que le bruit des trains causait moins de troubles du sommeil que le bruit de trafic routier. L'analyse en laboratoire des résultats de cette étude n'était pas totalement terminée et les résultats sur la qualité subjective du bruit demandent à être présentés.

2-4 Les limites supérieures

Un modèle a été suggéré par Griefahn (22 et 23) pour protéger des réveils et des altérations mineures du sommeil. Pour les bruits intermittents, le niveau sonore ne doit pas excéder respectivement 53 LAmax et 47 LAmax.

Kozarny (19) a suggéré que les niveaux en Leq hors des écoles maternelles ne doivent pas excéder 60 LAmax pour protéger le sommeil des petits enfants.

En accord avec les recommandations de l'OMS (24), le niveau sonore à l'intérieur ne doit pas excéder 45 LAmax et le niveau en leq 30 dBA. Ces recommandations de l'OMS sont bien en accord avec les découvertes en laboratoire et les recherche in situ rapportées dans cette conférence (5, 6, 22 et 23).

2-5 L'évaluation des mesures anti-bruit (écrans, doubles vitrages, régulation du trafic)

Il y a énormément d'études sur ce thème. Une étude publiée depuis le dernier ICBEN (Öhrström et al 25) montre que la diminution du nombre de véhicules lourds pendant la nuit n'a pas un effet significatif sur la qualité du sommeil.

2-6 Les activités diurnes

Depuis toujours aucun effet en terme de troubles physiologiques de la santé dus aux troubles du sommeil par le bruit n'a été prouvé. Si ces effets existent, il sera très difficile de prouver des interactions entre les différents facteurs individuels et ceux de l'environnement. La recherche de tels effets continue mais les nouvelles études portent sur les effets secondaires par exemple sur les activités diurnes et la somnolence pendant la journée et les mesures antibruit comme l'utilisation de pilules pour dormir et de bouchons d'oreilles. Pour cette hypothèse aussi, des nouveaux tests de performance plus sensibles doivent être développés.

3- Résumé

En résumé, plus d'efforts de recherche sont nécessaires dans les 6 domaines mentionnés plus haut. Pour répondre à ces questions, les recherches en laboratoire et sur le terrain sont toutes deux nécessaires. Nous croyons toutefois qu'une attention spéciale doit être apportée sur l'évaluation à long terme des effets sur la santé et sur les effets à long terme des mesures antibruit touchant divers groupes de population.

Ce type de recherche est très consommatrice de temps et une collaboration entre les équipes de recherche et l'agrément (enfin) de méthodes communes seraient très profitable.
Nous croyons qu'un atelier pourrait arranger non seulement notre groupe Sommeil mais aussi ceux qui travaillent sur d'autres thèmes spécialement sur les réactions sociales et sur la performance. Celà serait très utile pour les discussions et les collaborations dans les études futures.

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RANDOM EFFECTS MODELS FOR THE STUDY OF NOISE DISTURBANCE

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1. Introduction

Many studies which aim to assess the impact of a noise source on the population exposed to that source have as their outcome variable the probability that an individual is disturbed by a particular noise level. To ascertain at what threshold of noise individuals are likely to become disturbed it is common to subject a number of individuals to a number of stimuli. In this way each experimental subject experiences a series of repeated observations. If the data from such an experiment are included in the analysis at the same time then one of the fundamental assumptions of classical statistical analysis is broken namely that each observation is independent of all other observations.

For some time it has been possible to control for this problem in simple analyses by using a technique known as repeated measures analysis of variance. However there are two drawbacks to this approach. First it will not yield an expected probability that an individual will be disturbed by a particular noise level and second it does not easily allow covariates to be included in the predictive model. For example one may wish to know whether individuals with different socio-economic or demographic characteristics vary in their probability of being disturbed. This paper describes a new approach which overcomes these drawbacks and permits multivariate predictive models which control for repeated observations to be developed

2. The Study

The data on which this paper is based come from a large United Kingdom study which was sponsored by the Department of Transport as part of a review of night restrictions around major UK airports. The objectives of this study were to determine (a) the relationships between outdoor aircraft noise levels and the probability of sleep disturbance and (b) the variation of these relationships with time of night. It was carried out by the Civil Aviation Authority in conjunction with teams from the Universities of Loughborough, Manchester Metropolitan University and Southampton.

The study used as its basic data tool a new technique called actimetry which was chosen instead of the traditional method of measuring sleep - electroencephalography ('sleep-EEG'). Measuring sleep EEG is an expensive complex process which involves a large number of measurements and it is thus usually confined to small numbers of experimental subjects. Actimetry on the other hand is a simple, cheap method which measures fine limb movements - in this case arm movements. This permitted the study to measure a large number of individuals in their own homes. This study was developed after a pilot which demonstrated that actimetry based disturbances correlated strongly with those from sleep EEG disturbances.

A total of 400 subjects at 8 sites were studied, each for a period of 15 nights. The 8 sites (two each at London-Heathrow, London-Gatwick, London-Stansted and Manchester) were chosen (a) to cover a wide range of nighttime aircraft noise exposures (L_{eq}) and widely different combinations of event noise levels and numbers; (b) to be large enough to provide statistically adequate samples of residents but small enough to limit the variation in outdoor noise exposure; and (c) to be free from excessive noise from non-aircraft sources.

After losing a very small number of subject nights due to equipment failure the 400 subjects were monitored for a total of 5742 subject nights. In total some 40,000 subject hours of sleep data were analysed, broken down into more than 4.5 million 30 second epochs.

Outdoor aircraft noise levels (L_{AMAX} and SEL) were measured at up to three positions at each site using noise monitors set to record all levels in excess of 60 dBA. Aircraft movements were identified from runway logs and the events timed accurately for synchronisation with the sleep measurements. A total of 4823 aircraft events were logged during the 120

measurement nights. The study is described more fully in Ollerhead et al (1992).

3. Statistical Methodology and Results

The proportion of epochs with movement arousals for all subjects, all causes, all nights, all epochs was 5.3%, corresponding to around 45 arousals per night. In epochs with an aircraft noise event this rose to 6.18%. The aim of the following analysis is to assess this difference was statistically significant after controlling for the fact that each individual will have been observed in very many epochs. It is thus possible that an extremely sensitive individual may contribute very many disturbances and thus bias the overall results.

The basic outcome variable was dichotomous and indicated whether or not an individual was disturbed in a particular epoch. If one were only interested in comparisons of the number of disturbances in epochs in which there was no aircraft noise event (ANE) compared with those in which there was an ANE then repeated measures analysis of variance would be an acceptable technique. However to understand the relationship between sleep disturbance and aircraft noise properly a number of covariates need to be accounted for and so a multiple regression like approach is required. Ordinary least squares regression is biased for dichotomous dependent variables and so the appropriate method is logistic regression as used by Diamond et al (1987). The logistic regression model takes the form

$$\ln\left(\frac{p}{1-p}\right) = b_o + \sum_K b_K X_K + e = E \qquad (1)$$

where p is the probability of an individual being disturbed in an epoch

b_0, b_K are estimated regression coefficients

X_K are covariates

e is a random error term.

The logistic regression equation can be estimated straight forwardly and has the advantage that interpretation is simple. The effect of an individual covariate X_K can be measured in terms of the odds ratio - a measure similar to a relative risk - which can be calculated by exponentiating b_K, the appropriate regression coefficient. Also the estimated probability of disturbance for an individual with characteristics $\{x_i;\ i=1,\ldots,K\}$ can be calculated from equation (1) using the formula

$$\hat{p} = \frac{e^E}{1+e^E}$$

The use of logistic regression would be an improvement over the use of ordinary least squares regression but would still violate the assumption that the observations should be mutually independent of each other. This study developed a method based on random effects logistic regression to overcome the problem of individuals having repeated (and hence potentially correlated) observations. The random effects approach divides the error term into two parts $e = \varepsilon + u_i$ where ε is the stochastic random error and u_i is a systematic mean error which differs randomly between subjects.

Theoretically one could determine u_i broadly by introducing say a separate dummy variable into the equation for each individual and night. However this is in practice not possible as the very large numbers of dummy variables required would render the analysis at best uninterpretable. Therefore it is assumed that $u_i \sim N(0,\sigma)$ or $u_i = \sigma\delta_i$ where $\delta_i \sim N(0,1)$. The term σ is known as the random effect. The model can now be expressed as

$$\ln(p/1-p) = b_o + \sum_K b_K X_K + \sigma\delta_i + \varepsilon$$

The model can be estimated using maximum likelihood and is described fully in Egger (1992), Diamond et al (1993), Curtis et al (1993).

The interpretation of the regression coefficients is as for logistic regression but that for the random effect requires some explanation. The estimation of σ has an associated standard error. The hypothesis H_o: $\sigma=0$ can be tested using the test statistic $t = \frac{\sigma}{se(\sigma)}$. If this value is statistically significant then it can be concluded that there is evidence of important individual differences in the probability of disturbance. In such a situation the use of logistic regression without random effects would have been flawed.

The random effect can be thought of as a variable which increases or decreases the probability of an individual being disturbed (depending on the sign of the random effect) over and above that which would be expected given their observed characteristics. In this way it can be thought of as an indicator of individual disturbability.

The value of e^{σ} can be thought of as the average odds of being disturbed relative to some baseline and, as v_i is a random N(0,1) variable, the approximate 95% confidence interval for the individual differences can be given by $\pm 2\sigma$. Thus it can be inferred that among individuals with observed characteristics $\{X_i;\ i=1,...,K\}$, a particularly arousable person would have a probability of disturbance which could be inferred from the random effects logistic regression equation $\ln(p/1\text{-}p) = b_0 + \sum_K b_K x_K + 2\sigma$ and similarly an individual who was very difficult to arouse would have a probability of disturbance which could be inferred from the equation $\ln(p/1\text{-}p) = b_0 + \sum_K b_K x - 2\sigma$.

Ollerhead et al (1992) describe many analyses using this approach. For this exposition a simple model is described. The aim is to identify the factors most associated with disturbance in noise epochs. Therefore the outcome variable is whether or not an individual was disturbed in an epoch during which there was an ANE. To eliminate the possibility that a disturbance was caused by a previous ANE this analysis uses only those ANEs which occurred after a gap of at least five minutes since the previous ANE. A total of 31,109 ANEs were considered.

A total of forty independent variables were considered in this analysis but only four were significant predictors. These were time of night, noise level, sex of subject and the extent of disturbance in the period since the last ANE. Each of these was considered as a categorical variable as shown in Table 1. In order for the model to be identifiable it is necessary for one category to be the reference category. This reference category is constrained to equal zero and the coefficients for other categories for that variable should be interpreted relative to that reference category.

The results are presented in Table 1. A simple indicator of whether an individual coefficient for a category is significantly different from the reference category is found by dividing the coefficient by its standard error with a critical value of around 2 at the 5% level of significance. The results can be summarised as:

i) as disturbance in the quiet period before the ANe increases there is a corresponding increase in the probability of disturbance in the ANE. Exponentiating the coefficient gives an odds ratio which in this case indicates that an individual with a rate of 5-10 disturbances per hour in the quiet period is $e^{0.25} = 1.28$ times more likely to be disturbed in the ANE than a counterpart who was not disturbed.

ii) women are less likely to be disturbed than men

iii) noise level only becomes important above an L_{AMAX} of 80dBA.

iv) the probability of disturbance increases greatly as time of night increases.

v) the "random effect" is significant. This is an indicator of individual disturbability and suggests that an individual who is one standard deviation above the mean is $e^{0.32} = 1.37$ times more likely to be disturbed by an ANE than a counterpart who was "averagely disturbed".

These results are discussed more fully in Ollerhead et al (1992) but this last result deserves fuller attention. As described above individual variability gives an index of disturbability. Remember that it is assumed to take a normal distribution. Therefore around 95% of the population could be assumed to lie between two standard deviations above

and two standard deviations below the mean. An individual two standard deviations above the mean - and hence one who would be very disturbed - would be around 1.85 times more likely to be disturbed than the average person. It should be stressed that these results are net of all other individual characteristics. Indeed the chance of a highly disturbable person (two standard deviations above the mean) being disturbed by an ANE is 3.5 times higher than that of a person who is not very disturbed (two standard deviations below the mean). This degree of variation is greater than for any of the other independent variables studied thus far.

4. Summary

This paper has described a new approach to study the effects of individual characteristics on individual disturbance when each individual is exposed to more than one event. In particular it describes an approach which permits the quantification of unobservable factors such as individual disturbability to noise. The approach is illustrated using data from the 1992 UK Sleep Disturbance study and finds that for these data individual disturbability is the most important factor affecting disturbance due to aircraft noise.

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Table 1 : Random Effects Logistic Regression of the Probability of being Disturbed in an Aircraft Noise Epoch

Variable		Coefficient	Standard Error	Odds
Constant		-3.08	0.08	
Sex:	Male (Reference)	0.00	-	1.00
	Female	-0.17	0.06	0.84
Noise Level (L_{AMAX}):	< 65	0.00	-	1.00
	65-69	-0.21	0.09	0.81
	70-74	-0.09	0.07	0.91
	75-79	0.01	0.08	1.01
	80-84	0.20	0.08	1.22
	> 85	0.34	0.08	1.40
Disturbances per hour in quiet epochs since last ANE:	0	0.00	-	1.00
	0-5	0.10	0.06	1.11
	5-10	0.25	0.05	1.28
	> 10	0.26	0.05	1.30
Time of Night:	1130-0100	0.00	-	1.00
	0100-0230	0.07	0.06	1.07
	0230-0400	0.16	0.05	1.17
	0400-0530	0.17	0.05	1.18
Individual Disturbability:	Estimate	0.31	0.03	
	Odds 2SDs above mean	-	-	1.85
	Odds 2SDs below mean	-	-	0.53

CHAIRMAN'S REPORT AND INTRODUCTION TO THE SESSIONS OF INTERNATIONAL NOISE TEAM 6

(former title: GENERAL DEVELOPMENTS IN COMMUNITY RESPONSE RESEARCH)

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INTRODUCTION

Mister chairman, ladies and gentlemen,

During the past five years community response research has flourished in many countries, especially in Western Europe and Japan. This is reflected in the large number, more than 60, of contributions from this field of research at this congress.

The major developments during the past five years are reflected in the choice of the invited papers, and in the clustering of mutually related free contributions.

Unfortunately, the multitude of free communications made it impossible to grant all authors sufficient time to give oral presentations. Therefore it was decided that all free communications would be presented as posters.

However, in recognition of the importance of these posters, our special poster session will take place from 5.30 to 6.30 this afternoon. At that time, the authors will be at their posters to explain their work. Those of you who I have seen carefully reading these posters over the last few days will, I am sure, agree that these posters are an important part of the Team 6 program.

In the remainder of this paper the achievements of the past five years are described, and the sessions are introduced.

COMMUNICATION

Since the 1988 meeting of ICBEN in Stockholm a systematic attempt has been made to coordinate Team 6 activities. Correspondence has been exchanged, and members informed the chairman about the activities in their countries or regions of the world.

Unfortunately the much appreciated systematic feed back, to be realized by the creation of the ICBEN Bulletin did not start off successfully. At least four publications were planned. It was published thrice. We did not have an entry for the first and second edition, but we published our report in the third one and prepared the information for the fourth one, which never was published.

During the period 1988-1993 the Team consisted of a chairman, a co-chairman and members, together representing eleven different countries, with as wide a geographical spread as possible. Membership is given in Table 1.

Table 1 Members of International Noise Team 6: Community Response to Noise, during the period 1988-1993

Ronald G. de Jong	Netherlands	chairman
James M. Fields	USA	co-chairman
A. Lex Brown	Australia	
Ji-Qing Wang	China	
Michel Vallet	France	
Bernd Rohrmann	Germany	
Kiyoto Izumi	Japan	
Takashi Yano	Japan	(from 1.7.92)
Truls Gjestland	Norway	
Birgitta Berglund	Sweden	
Selma Kurra	Turkey	
Christopher G. Rice	UK	(till 1.6.92)
Ian H. Flindell	UK	(from 1.6.92)

During this period the ICBEN Constitution allowed no more members. If the Constitution is modified to permit a larger membership - which is being considered at the time - then our membership would be expanded in the future. If this change takes place then I offer the following message to all researchers working on community response. If you consider yourself one of the leading researchers in your country, and you would be prepared to invest a couple days per year representing your country, which mainly means assembling and distributing information, please feel free to contact my co-chairman, Jim Fields, or myself, to express your interest in a possible membership.

GOALS AND ACHIEVEMENTS

During the last ICBEN meeting, in Stockholm, 1988, the following goals were given a high priority for research in the 1988-1993 period:

Table 2 Research goals set for 1988-1993

annoyance model methodology
low noise exposure criteria
noise abatement
team collaboration

What has actually happened? There has been some cooperation. We have lent assistance to some researchers and there has been at least one instance of cross-national cooperation which was fostered by the contacts established through ICBEN. In general, however, a programmatic approach such as was formulated in 1988 was not realized. Indeed community response seems to have a demand-led rather than a fundamental research orientation, as my predecessor, professor Chris Rice, pointed out at the end of his term.

As a result only a limited effort was invested in the first two research goals. Governments have expressed hardly any interest in those areas. The most prominent attempts to at least travel a part of the road leading to these goals stem from the United states. I am mainly referring to the work of Dr. Fidell and others, and to Dr. Fields' work.

Topics that have enjoyed much attention are: aircraft noise, with special attention to helicopter noise and night time noise; impulse noise; and urban noise. Furthermore in Japan and England there has been a noticeable revival in the interest in railway noise.

Team collaboration, though on a modest scale, occurred several times. Mostly this collaboration meant conveying information. But on several occasions also working together in research projects was realized. Still, programmatic collaboration has no major influence. As long as research on community response will be driven mainly by short term political interest, and this interest will differ a lot from country to country, this goal will not be reached. Even under these restricting circumstances I would suggest that we can make much more use of each others knowledge than we have up to now. Communication is the magic word.

INTRODUCTION OF THE SESSIONS

Now we arrive at the topic of this conference. As I mentioned before, altogether, the invited papers, the oral communications, and the posters add up to over 60 contributions in the field of Community Response. The invited papers, and the mini-sessions, reflect the issues around which much research activities have been concentrated during the last period.

The time allotted to this plenary session will consist of a short introduction by the chairman, followed by four carefully selected but succinct 'position' papers, each allocated 25 minutes for presentation, and followed by 15 minutes of introduced open discussion.

The first invited paper addresses the role of ambient noise in evaluating a target noise. The author is Dr. Fields, USA, while the lead discussant will be Professor Berglund from Sweden.

The second paper, by Dr. Buchta from Germany, gives a review of research on impulsive noise and a thorough evaluation of a possible penalty for impulse noise. Dr. Berry (UK) will open the discussion on this item.

After the coffee break Dr. Miedema from the Netherlands will address the issue of response functions for environmental noise (relating to the question: "Is all noise the same?"). Professor Diamond (UK) will be the lead discussant for this intriguing issue, which has caused many controversies over the past decade.

Last, but not least, Dr. Lambert, one of our French hosts, will give a presentation on the social impact of noise prevention and reduction measures. Dr. Aubrée, also from France, will open the discussion.

This plenary session is not the first Team 6 session of this conference. Already this morning we have had two interesting sessions. One on the impact of non-acoustical parameters, and one on the evaluation of alternative noise descriptors.

Nor will this plenary session be the last one of the Team. First, falling in behind this session, you are all invited in the Espace Rhodes to take note of the many posters, and to discuss with the authors. Many interesting and valuable contributions can be encountered there. Unfortunately the time schedule for this congress is so tight, that we could not offer all authors the opportunity to read their paper. Having a poster by no means, and I want to stress this, by no means implies that the contribution would not be of an excellent quality. So come, and see, and convince yourself.

Tomorrow we have three other small sessions. One on reactions to changes in noise environments, with Dr. Ollerhead (UK) as the lead discussant. A second session will be devoted to evaluating the response to impulse noise. Work on impulse noise proved to be quite prominent over the past five years and also seems to continue this way. As a result, a separate impulse noise session, in addition to Dr. Buchta's invited paper, was warranted. Dr. Vos (The Netherlands) will start the discussion. The third small session, with lead discussant Dr. Brown (Australia), will address the annoyance in non-residential settings.

This approach makes good use of the limited time available and appears to meet the Objective of the ICBEN, which is to "encourage international cooperation in the study of the biological effects of noise; to promote communication among research scientists, government agencies, industrial workers and managers, and other parties and entities concerned with noise and noise effects; and to stimulate the exchange and dissemination of information about the biological effects of noise." I hope you will appreciate the sessions of Noise Team 6 as stimulating ones.

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THEORIES AND EVIDENCE ON THE EFFECT OF AMBIENT NOISE ON REACTIONS TO MAJOR NOISE SOURCES

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ABSTRACT

This paper reviews nine hypotheses and the evidence from 28 social survey findings about the relationship between residents' annoyance with a major noise source and the acoustical context in which that noise is experienced. Three bases for deriving these hypotheses are identified: acoustical, normative, and environmental. The best available evidence from these surveys of residents' reactions to aircraft and other noise under varying ambient noise conditions indicates that ambient noise in residential areas does not have an important impact on target noise annoyance. Better information about ambient noise effects will require tests of theories of ambient noise effects, stronger study designs and appropriate analysis techniques.

THÉORIES ET ÉVIDENCE SUR L'EFFET DE BRUIT ENVIRONNANTE SUR LES RÉACTIONS À PROPOS D'UNE SOURCE DE BRUIT GRAVE

Cet article évalue neuf hypotheses et l'évidence de plus que vingt études concernant la relation entre nuisance des zônes d'habitations par une source de bruit grave et le contexte acoustique où on éprouve ce bruit. On a identifiqués trois principes d'où on peut dériver ces hypotheses: acoustique, normatif et l'environment. Les meilleures preuves disponibles de plus que vingt revues des réactions des habitants à propos des avions et autre bruit sous des conditions de bruit environnante differents indiquent que le bruit environnant dans des régions habitants n'a pas une influence importante dans l'objectif de bruit nuisance dans ces études.

INTRODUCTION

This paper reviews the theories and evidence about residents' reactions to a major noise source (a target noise) in the presence of a second noise source (an ambient noise). A common assumption is that residents' annoyance with a target noise will be reduced in the presence of a loud ambient noise. The assumption is obviously justified if a target noise is rendered totally inaudible by an ambient noise. The assumption is buttressed by fundamental knowledge about the perception of the loudness of tones in the presence of simultaneously presented ambient noise. When the tone and ambient noise are simultaneously presented, there is partial masking. The perceived loudness of the target sound is reduced even though it is still audible (Stevens and Guirao, 1967). Several laboratory studies have found evidence that is consistent with a similar effect for annoyance judgments of more complex target noises (e.g. aircraft) against a simultaneously presented ambient noise (Fidell, et al., 1979; Powell, 1979).

The above findings provide valuable predictions but do not provide firm evidence for determining whether annoyance with an audible target noise in a residential setting will be affected by the more general exterior ambient noise context in which it is experienced. Specifically, it is not clear whether residents' annoyance with one transportation noise source will be affected by the presence of another environmental noise source (usually another transportation noise source). If the

energy-averaging indices are correct, then even total masking of half of the target noise events would generate only a moderate 3-decibel effect on annoyance. For a continuous target noise (e.g. road traffic noise) in the presence of an intermittent ambient noise (e.g. aircraft noise) a masking of even half of the continuous noise events is unlikely. It is also not clear whether exterior environmental noises are important sources of masking noise in a home environment which contains a large amount of self-generated sound from speech, appliances and audio equipment.

This paper reviews the evidence from 28 findings about the annoyance with target noises in residential areas, identifies three theoretical bases for ambient noise effects, discusses analysis techniques which draw new information from existing community surveys and points to needed improvements in new community studies. The evidence includes 6 surveys which were published since the last ICBEN conference in 1988 and updates the evidence from previously published analyses (Fields, 1992a; Fields, 1992b; Fields, 1993).

EVIDENCE FROM COMMUNITY STUDIES

Methodology An examination of over 670 publications from 328 social surveys of noise annoyance has identified the 28 study findings listed in Table 1 which test the assumption that residents' reactions to one noise (a "target" noise) are affected to an "important" extent by ambient noise exposure. The residents' reactions are measured with answers to social survey questions about the extent of annoyance or disturbance from the specified target noise. Five alternative criteria have been used in Table 1 to measure whether there are "important" observed differences between reactions in high and low ambient noise environments. In order of precedence these criteria are: (1) a difference in annoyance which is as large as that associated with a 3-decibel difference in target noise exposure [3dB], (2) a 5% difference in the percentage annoyed [$\Delta 5\%$], (3) an accounting for 1% of the variance in annoyance [$.01r^2$], (4) a $p<.05$ statistically significant difference [$p<.05$], or (5) an unqualified *verbal* statement supporting an effect [Vb]. A detailed description of the methodology has been published (Fields, 1992a).

Results The pie charts in Figure 1 divide the study findings between those supporting an "important" tendency for higher ambient noise to decrease annoyance, those supporting an "important" tendency for ambient noise to increase annoyance and those finding no important effect. The divisions of the charts are based on either the numbers of studies (first column) or the numbers of responses in each study (second column). The numbers of findings and responses appear beside each pie slice. For the first four pairs of charts, the total numbers of studies and respondents below each pie [in square brackets] are smaller than the sums of the slices (in parentheses) because respondents in five of the 23 studies independently evaluated two target noises (e.g. both aircraft and road traffic).

The first pair of charts ("All findings") summarizes the total evidence from 23 studies in which 29,308 respondents made 34,456 evaluations of 28 different target noises. About 23 to 25% of the evidence finds support for the conventional ambient noise assumption (higher ambient noise decreases target noise annoyance); 64-71% finds that ambient noise has no "important" effect and 5-11% finds ambient noise increases annoyance.

The remaining charts in Figure 1 assess the possibility that an ambient noise effect could have been obscured by some types of methodological weaknesses or by the type of noise source. Each of these charts excludes some of the findings which appeared in the "All findings" charts (Row A). Findings for only aircraft noise annoyance are presented in rows E, F and G. Row H presents findings from studies which did not measure ambient noise levels but instead utilized surrogate indicators by contrasting reactions in urban and rural areas or in predominantly industrial and

residential areas.

Three progressively more exclusive definitions of the quality of the findings are presented in Figure 1. The "Standard" findings (Rows B to G) must control for both target and ambient noise level in the analysis and measure the effect size using a 3dB, Δ5%, or $.01r^2$ criterion. The rationale for this definition has been presented previously (Fields, 1993). In addition to meeting the "Standard" requirement, the "Standard + better quality noise" findings (Rows C, D, F, G) must either be based on direct noise measurements or on moderately sophisticated noise estimation methods (aircraft noise must be adjusted for variations in operating conditions while road traffic noise must be adjusted for at least the number of vehicles at a site and the distance of dwellings from roads). "Standard + 20 dB range" findings (Rows D and G) meet the previous criteria and also include a 20 dB range in ambient noise exposure.

The data in Figure 1 show that the majority of the evidence from all analyses supports the conclusion that ambient noise does not have an important effect on annoyance in these studies.

EXAMINING THEORETICAL BASES FOR EXPECTING AN IMPACT

Most previous social survey publications have hypothesized that ambient noise would decrease annoyance with aircraft or other "target" noises, but have not been explicit about the theoretical bases for the hypothesis. Several discussions have advanced theories. Powell (1979) has applied a theory of inhibition of annoyance to analyze results from a laboratory study of the annoyance with a total noise environment consisting of multiple sources. Miedema (1984) has provided a review of the literature which highlights both masking and annoyance sensitivity theories of ambient noise effects. The remainder of this section considers three theoretical frameworks to derive nine explicit ambient noise impact hypotheses. Six of the hypotheses predict that higher ambient noise decreases target noise annoyance. Two hypotheses, the sensitizing and synergistic nuisance hypotheses, predict that higher ambient noise increases target noise annoyance. One hypothesis, the independent judgment hypothesis, predicts that ambient noise does not affect target noise annoyance.

Acoustical phenomena A ***masking hypothesis*** assumes that ambient noise levels mask some target noise events and thus effectively reduce exposure and the resulting annoyance. An ***alerting hypothesis*** assumes that as the target noise events intrude higher and higher above the ambient noise the target noise involuntarily and annoyingly demands residents' attention. An ***anchoring hypothesis*** assumes that the ambient noise provides an acoustical calibration point against which target noise is compared. A ***sensitizing hypothesis*** assumes that higher ambient noise exposure creates increased sensitivity with noise generally.

Personal values Both of these hypotheses assume that quiet neighborhoods either attract or produce residents who are either more sensitive to noise or who place a greater value on quiet environments. A ***quietness norm hypothesis*** assumes that low ambient noise neighborhoods tend to include residents who highly value quietness. An ***escape norm hypothesis*** assumes that low ambient noise neighborhoods tend to include residents who place a high value on their residence as a location for escaping from crowded, technologically complex, and, incidentally, noisy urban environments.

Nuisance definition A ***baseline nuisance hypothesis*** assumes that ambient noise implicitly creates a local definition of an unavoidable noise nuisance against which all other noise nuisances are judged. A ***synergistic nuisance hypothesis*** assumes that the combined effect of ambient noise and target noise nuisances is to broaden the definition of noise nuisances generally.

Comments While each hypothesis is reasonable, a more careful examination suggests reasons why, as the evidence in Figure 1 suggests, each of the theories might be rejected. For example, the *anchoring* and *sensitizing hypotheses* are weakened by that fact that residential environments include other, more pervasive sounds (voices and household appliances) for calibration points. The *personal value* hypotheses must consider the fact that most previous surveys have not found a relationship between general noise sensitivity and environmental noise levels (Fields, 1992a:25).

Alternative approaches The simple alternative to the previous eight hypotheses is an ***independent judgment hypothesis*** that assumes that residents judge each environmental noise source independently. The hypothesis assumes, for example, that residents draw on deep-seated values to evaluate the importance of quiet, and use broad-based political/environmental standards to define nuisances.

Another alternative is to recast the ambient noise issue in more complex terms. This perspective suggests that we should not simply be asking "Does ambient noise affect target noise annoyance?" Instead, we should be asking "Are there specific types of situations in which ambient noise affects annoyance and other situations in which ambient noise does not affect annoyance?" This perspective leads to a restatement of some of the previous nine hypotheses into such speculative, more complex hypotheses as the following: the *alerting hypothesis* is restricted to new residents who have not yet learned to expect intrusive sounds; the *masking hypothesis* is restricted to relatively low-level intermittent target noises (measurable effects are only expected for surveys if inaudible noise events have been included in the calculated noise exposures); the *anchoring hypothesis* is restricted to individuals with very quiet total personal noise exposures; the *baseline nuisance hypotheses* is restricted to clearly preventable target noises in areas that do not contain important non-noise problems; the *escape norm hypothesis* is restricted to rare, truly remote areas where individuals are removed from contact with the manifestations of a technological society (e.g. shopping centers) which are found in suburban and most rural areas.

Inadequate bases Any of the above hypotheses could provide a logical framework for developing a theory of ambient noise effects. However, two fundamental confusions have provided inadequate, less logical support for conventional ambient noise theories.

First, the concept of the comparative ranking of two noises is sometimes confused with the direct rating of the level of annoyance with a single target noise. Which of two noise sources will be comparatively ranked as being relatively annoying will vary with the relative noise levels of the two sources. However, the level of annoyance with each of the individual sources may be completely unaffected by the presence of the second source. Just because one noise source is the "lesser of two evils" may not make that noise source any more acceptable than it would be in the absence of ambient noise.

Second, the concepts of private annoyance feelings and public complaint actions are often confused. Acousticians' and administrators' experiences come primarily from public complaints which, unlike private annoyance, may well be associated with ambient noise. Such an association would be expected if protest organizations direct their limited resources at only one problem at a time, the worst of the worst problems, despite the fact that the importance of other problems is undiminished.

PROPOSED APPROACH TO FUTURE ANALYSES

The balance of the evidence in Figure 1 indicates that ambient noise did not have an "important" impact in most of these studies. However, the published analyses which generated these findings could conceal an impact which has important policy implications. An impact which

appeared to be relatively unimportant in some studies, because only a narrow range of ambient noise differences was considered, might be important for a policy which considers a very wide range of ambient noise exposures. An impact might also have been concealed if a more complex ambient impact model is appropriate. Two analytical approaches help to address these possibilities.

Equivalent impact ratio In this paper the term "equivalent impact ratio" (R) refers to a measure of ambient noise impact which is unaffected by the range of ambient noise which happens to be included in a study. If annoyance is regressed on noise level, the equivalent impact ratio is formed by dividing the unstandardized regression coefficient for ambient noise by the coefficient for the target noise. The ratio can be estimated from either linear or non-linear regression analyses. A value of R=0.2 indicates that a one-decibel change in ambient noise displaces a dose/response curve by only 2/10 of the distance which is caused by a one-decibel change in target noise. The standard error of the equivalent impact ratio provides a direct test of the statistical significance of the ambient noise effect and could be used to differentially weight estimates from several studies (on the basis of their precision) to form a pooled, best estimate of the ambient noise effect.

Examining more complex models The more complex, alternative hypotheses which were suggested above imply that analyses must be more complex. Some hypotheses imply that a more complex noise metric than L_{Aeq} or DNL is needed to characterize the noise exposure (for example a spectra-dependent measure of detectability). While such frequency-spectra data are not available from existing surveys, routinely gathered noise data can be used for other analyses. All of the hypotheses imply that there are interactions between the ambient noise level and either the target noise level or other variables. Visual displays of target noise dose/response relationships in different ambient noise groups are a simple but effective means of beginning any such exploration. More complex analyses need to based on models which include interaction effects which can be formally tested for statistical significance.

LESSONS FROM PREVIOUS STUDIES TO APPLY TO FUTURE RESEARCH

The amount of information that we can extract from previous studies is substantially limited by two aspects of the community survey publications. Firstly, these publications have not discussed, let alone tested, the mechanisms which are inherent in the nine ambient noise hypotheses which were outlined above. Secondly, the surveys do not provide detailed information about the noise environments. The surveys have not, for example, indicated whether any of the target noises are ever inaudible at outdoor locations. Some surveys may have based aircraft noise estimates on annual flight traffic data without determining whether all types of flights in the flight traffic data are audible. Other surveys may have based noise estimates on observed noise events and thus automatically excluded inaudible events.

The review of these studies and of noise studies generally suggests that there is no guarantee that additional, similar ambient noise studies will generate useful new information. Future community research will only be valuable if future studies include the following practices: (1) carefully consider both complex and simple theories of ambient noise effects, (2) design samples and measurements to test the theories supporting ambient noise hypotheses, (3) estimate target and ambient noise levels which are uncontaminated by noise from other sources, (4) obtain highly reliable estimates of the target noise levels, (5) report absolute levels of annoyance rather than relative levels of annoyance with each noise source, (6) gather information on the audibility of the target noise, (7) report information about the intrusiveness of the target noise, (8) include large numbers of study areas, and (9) explicitly control for the effects of confounding area characteristics.

CONCLUSION

The best available social survey evidence (reviewed in Figure 1) does not support an ambient noise effect. Better tests of ambient noise hypotheses require that equivalent impact ratios and their standard errors be compared across studies and that the possibility of interaction effects and non-linear relationships be systematically explored. New studies will only be valuable if they direct their attention at specific, complex ambient noise hypotheses, design samples to test the hypotheses, collect and report relevant acoustical data, and select appropriate analysis techniques.

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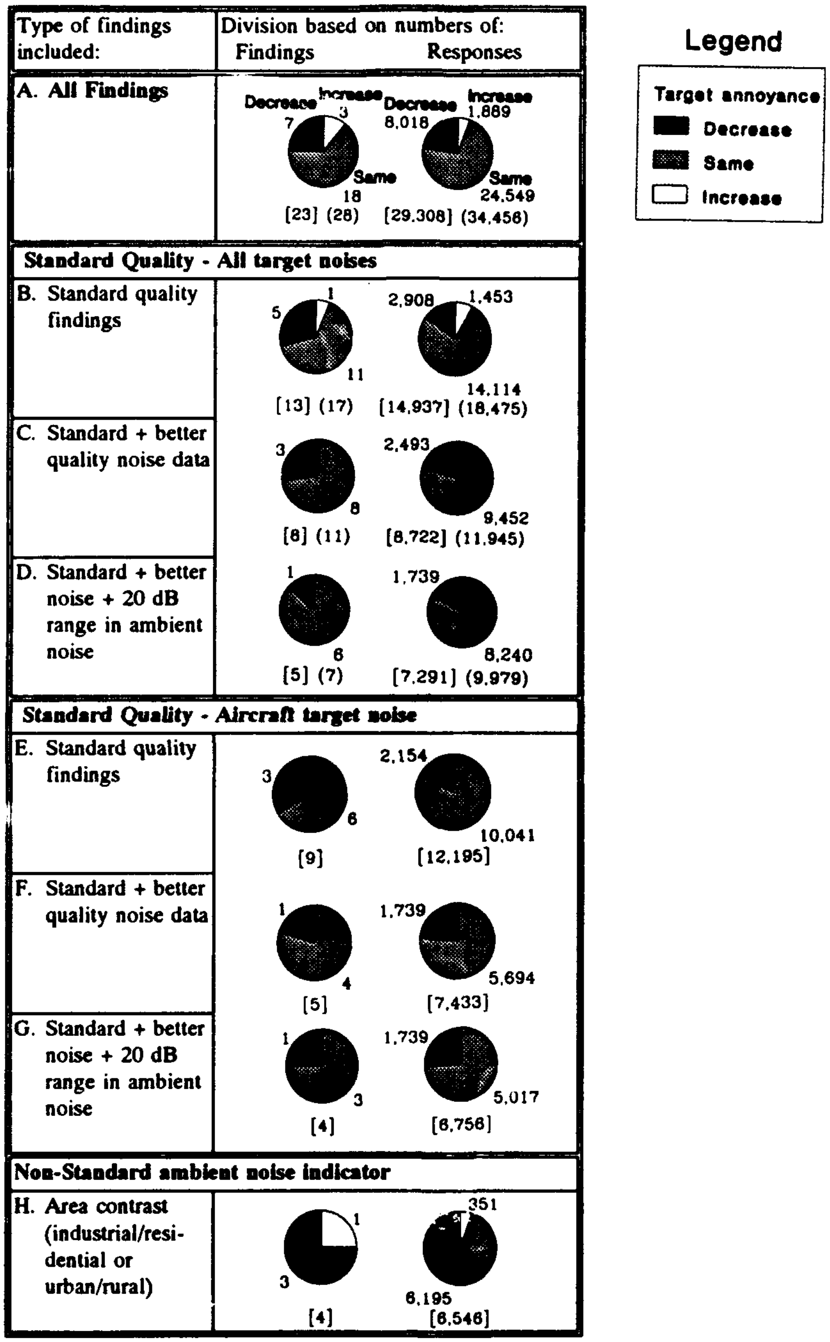
Table 1: Findings grouped by direction of ambient noise effect

Title[a] (Catalog ID from Fields (1991))	Criterion	Noise[b] Control (✓)	Noise[b] Quality	Ambient noise Type[e]	Ambient noise Range	Number of interviews
7 findings that ambient noise decreases annoyance						
1984 CEC Aircraft/**Road** (CEC-3[c])	3dB	✓	+	Air	24 L_{Aeq}	1,739
1989 Muroran **Road**/Rail (JPN-319[h])	3dB	✓	+	Rail	19 L_{Aeq}	204
1980 Salt Lake Rating [AIR] (USA-219)	3dB	✓		Comu	30 L_{Aeq}	100
1969 Mixed Road/**Aircraft** (UKD-033)	3dB	✓		Road	10 L10	315
1990 Toronto **Air conditioner** (CAN-322[h])	3dB	✓		Comu	16 L_{Aeq}[g]	550
1967 Heathrow **Aircraft** (UKD-024)	$.01r^2$	No		Road	22 PNDB	4,690
1986 Sydney **Aircraft**/Road (AUL-307)	Vb	No		Road	30 L_{Aeq}	420
18 findings that ambient noise has no important effect						
1984 CEC **Aircraft**/Road (CEC-3[c])	3dB	✓	+	Road	24 L_{Aeq}	1,739
1982 Heathrow **Air**/Road (UKD-241)	3dB	✓	+	Road	20 L_{Aeq}	417
1980's Brussels **Airport** (BEL-288)	3dB	✓	+	Comu	12 L_{Aeq}	677
1972 London **Construction** Site (UKD-074)	3dB	✓	+	Air Road	0 NNI 17 L_{Aeq}	535
1972 London **Construction** Site [AIR] (UKD-074)	$.01r^2$	✓	+	Road Const	17 L_{Aeq} 40 L_{Aeq}	535
1971 3-City Swiss **[AIR]** (SWI-053)	$.01r^2$	✓	+	Comu	28 L50	3,930
1971 3-City Swiss **[ROAD]** (SWI-053)	$.01r^2$	✓	+	Air	32 NNI	949
1978 Canada 4-**Airport** (CAN-168)	$.01r^2$	✓	+	Road	23 L_{Aeq}	670
1969 Mixed **Road**/Aircraft (UKD-033)	3dB	✓		Air	40 NNI	315
1989 Oslo **Airport** (NOR-311)	3dB	✓		Road	10 Ldn	3,337
1979 Swiss Gen'l **Aviation** (SWI-180)	Δ5%	✓		Comu	6 dB[f]	1,010
1972 Paris-Area **Railway** (FRA-063)	$p<.05$	✓		Comu	20 L_{Aeq}	350
CEC Impulse **[ROAD]** (CEC-4[d])	Vb	✓		Impulse	45 L_{Aeq}	1,610
1977 Dutch **Railway** (NET-153)	Vb	✓		Comu	7 L95	670
CEC **Impulse** Noise (CEC-4[d])	Vb	✓		Road	30 L_{Aeq}	1,610
1964 Oklahoma **Sonic Boom** (USA-012)	Δ5%	No		Area	NA	3,000
1977 Hampshire **[ROAD]** (UKD-160)	Δ5%	No		Area	NA	1,595
1978 Zurich Night **[ROAD]** (SWI-173)	Vb	No		Comu	NA	1,600
3 findings that ambient noise increases annoyance						
1975 British **Railway** (UKD-116)	3dB	✓		Comu	20 L_{Aeq}	1,453
1987 Seoul **Traffic** (KOR-295)	3dB	No		Area	NA	351
1968 Coventry **Railway** (UKD-029)	Vb	No		Nbr's	NA	85

Notes: [a]The target noise appears in bold print. [b]+="better quality noise" as explained in text. ✓=target noise is controlled for in the analysis [c]CEC-3= 3 surveys: FRA-239, UKD-238, and NET-240. [d]CEC-4= 4 surveys FRA-252 GER-253 IRE-254 NET-255. [e]"Comu" = Community noise, "Nbr's"= neighbors' noise. [f]Described only as "dB(A)" in a study publication. [g] 24-hour L_{Aeq}. [h] Consult the references for these two surveys which were published after the catalog (Bradley, 1993; Izumi and Yano, 1990).

Figure 1: Effect of ambient noise on target noise annoyance -- division of evidence



A REVIEW OF THE PENALTY FOR IMPULSE NOISE

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ABSTRACT

Both in the field and in the laboratory, it has been shown that for environmental sounds such as those from traffic or gunfire, the annoyance is well predicted by the equivalent sound-pressure level, L_{eq}. This does not mean, however, that road-traffic and shooting sounds with the same L_{eq} are also equally annoying. In the method of rating sounds with respect to the expected community response, the differences between dose-response functions may be accounted for by adding corrections or penalties. After a review of the utility of L_{eq}, the present paper is concerned with the dose-response functions for impulse sounds produced by small and large firearms. Results from field and laboratory studies already reported in the literature are supplemented with recently obtained results. Many data suggest that for impulse sounds produced by small firearms, a level-dependent penalty is relevant. Furthermore, the present results indicate that for impulses from large firearms, a level-dependent penalty may be not needed. The application of a penalty can be simply avoided by expressing the L_{eq} of the impulses from large weapons in dB(C).

EQUIVALENT SOUND PRESSURE LEVEL

As a method of rating sounds with respect to the expected community response, ISO/R 1996 (1971) recommends the measurement of the A-weighted equivalent sound pressure level, L_{eq}. For the prediction of the annoyance caused by road-traffic sounds the usefulness of L_{eq} has been demonstrated in various field and laboratory studies (Buchta and Kastka, 1977a, 1977b; Cermak, 1979; Voigt et al., 1974; Yaniv et al., 1982; Yeowart et al., 1977).

Field surveys

In the field, the question about the utility of L_{eq} as a predictor of annoyance caused by impulse sound cannot be easily answered: If a field study comprises the relevant acoustic and subjective data of only one noise zone, or, if a significant dose-response relationship is found around one shooting range only (e.g., see Heintz, 1980), a possible benefit of L_{eq} cannot be demonstrated because in such a case L_{eq} is highly correlated with most of the other acoustic measures.
In one of our investigations (Buchta, 1990) the data for about 400 randomly selected residents around two military and three civil shooting sites were collected. The results showed that for the prediction of the subjective effects of the sounds from small firearms, L_{eq} is superior to measures that ignore the number of acoustic events: The explained variance in the individual scores changed from 14% to 19% if A-weighted L_{eq} rather than the mean A,fast or A,imp levels of the individual shots were used as predictors.
In a field study on the annoyance caused by the sounds from large firearms (cannon 105 and 120 mm, mortar 120 mm, howitzer 155 and 203 mm), the relevant data for about 250 residents around the military training field of Grafenwöhr were collected (Buchta, 1988). The explained variance in the individual overall annoyance scores was 8% if the sound level of the impulses was expressed in dB(A,fast) and 12% if expressed in dB(C,fast). L_{eq} was the best predictor of the overall annoyance: both for the A-weighted and for the C-weighted energy, the explained

variance was about 19%.

The usefulness of L_{Aeq} was also tested in one of our recent field studies on the annoyance caused by artillery fire (Buchta, 1993, supported by the Ministry of Defense). Three pairs of noise zones were compared. In each pair the yearly number of shots differed to a great extent: ratios ranged between 1:24 and 1:33. However, due to considerable differences in the sound pressure levels of the bangs, as determined in the noise zones, the computed C-weighted L_{Ceq} within each pair of noise zones was almost equal. Between the pairs, L_{Ceq} ranged between about 50 and 70 dB(C). Since the mean annoyance reported by the two groups of respondents in each pair was not significantly different, we may again conclude that L_{Ceq} is an adequate predictor of annoyance indeed.

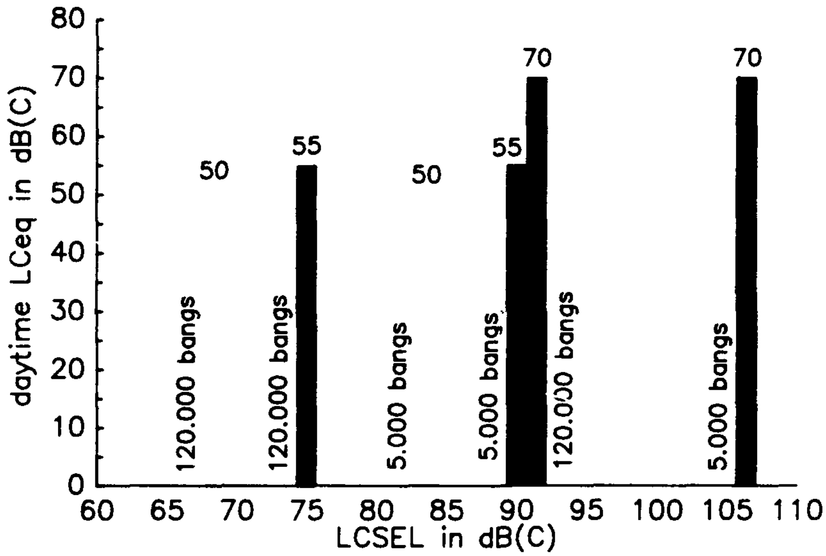

Fig. 1. Three pairs of noise zones with the same annoyance in each pair but different yearly number of bangs

Laboratory experiments

In the laboratory, the effectiveness of L_{eq} as a predictor of annoyance has been investigated by Vos and Geurtsen (1987). In one condition of their experiment, all impulse sounds had the same level, whereas in the other eight conditions the levels of the impulses could differ either by 6 or by 12 dB. The proportions of the impulses with high or low sound levels were 90% vs 10%, 75% vs 25%, and vice versa. The subjects compared the annoyance caused by the impulse sounds with the annoyance due to road-traffic sounds by adjusting the level of either road-traffic or gunfire sounds in such a way that these sounds were just as annoying as the standard gunfire or road-traffic sounds. The results from one group of subjects showed that the degree of annoyance was about the same for all conditions, whereas the results from another group of subjects showed that L_{eq} may overestimate the annoyance in at least a few conditions. These data therefore mildly support the effectiveness of L_{eq} as a predictor of annoyance.

The usefulness of L_{eq} has also been demonstrated in a recent study jointly conducted by Buchta and Schomer [Buchta (1993); Schomer et al. (1992)]. In a house very close to a military training field, more than 300 subjects were presented with real sounds produced by, amongst others, small firearms and wheeled vehicles. The study was designed as a paired comparison test where the subjects were presented with pairs of sounds and were asked, for each pair, to indicate which was more annoying, the first or the second sound. The beginning and end of each stimulus was indicated by lights separated by 30 s intervals. The level of the vehicle noise was changed by the use of different vehicles (gasoline-engine van, diesel Jeep, cargo truck, tank transport) rather than by changing the distance between the road and the test house.
On the basis of the responses of the subjects, the A-weighted sound exposure level, L_{ASEL}, of the vehicle noise was determined at which this control sound was as annoying as a specific kind of impulse sound (all levels determined at or close to the ears of the subjects). In one shooting condition, 60 shots were fired within a 30 s period and in another shooting condition 6 shots were fired within 3 or 30 s. For each of these conditions, there were three listening conditions: with windows closed, with windows partially open, and outdoors. Table I lists L_{ASEL} of the impulse sound in the various conditions, together with the estimated L_{ASEL} of the equally annoying vehicle sound. The resulting penalty for impulse sound is given in the last column. The data clearly show that in the 60-shots conditions L_{ASEL} of the equally annoying vehicle sound is 10 dB higher than in the 6-shots conditions. These results therefore support an equal-energy model. Fig. 2 shows the average annoyance penalty for near and far gunfire with subjects sitting in rooms with closed and opened windows and outside of the testhouse.

Table I. L_{ASEL} and L_{Aeq} of the sound of passing wheeled vehicles at which this sound was rated to be as annoying as gunfire, for various conditions. Based on data from Buchta and Schomer (1993).

		gunfire		vehicles		penalty	
number of shots	listening condition	L_{ASEL} in dB	L_{Aeq} in dB	L_{ASEL} in dB	L_{Aeq} in dB	L_{ASEL} in dB	L_{Aeq} in dB
60/30s	windows closed	50.9	36.5	63.5	50.9	12.6	14.4
	windows open	60.5	44.8	67.5	54.5	7.6	9.7
	outdoors	80.2	68.3	86.5	74.7	5.9	6.4
6/3s	windows closed	42.0	32.0	54	41.2	12.8	9.2
	windows open	51.8	37.3	58	45.5	6.5	8.2
	outdoors	71.7	59.9	75	64.4	4.0	4.5

PENALTY FOR IMPULSE NOISE

In the previous section it was shown that also for impulse sounds annoyance is well predicted by L_{eq}. This does not mean, however, that road-traffic and shooting sounds with the same L_{eq} are also equally annoying. Similarly, equal L_{eq}-values for shooting sounds produced by small and by large firearms do not necessarily guarantee equal degrees of annoyance. In the method of rating sounds with respect to the expected community response, the differences between dose-response functions may be accounted for by adding corrections or penalties.

In general, these penalties are computed relative to the dose-response relationship for road-traffic sounds. The penalty for a specific environmental sound has to be added to its L_{eq} to find the L_{eq} of the equally annoying road-traffic sound.
Several studies indicate that there are conditions in which the difference between dose-response functions cannot simply be canceled by application of a single-number penalty: in these latter conditions, the penalty should be level dependent.

Penalty for sounds produced by small firearms

Since the annoyance is only in part determined by Leq, i.e., the correlation between the dose and the response is relatively low [see, e.g., Job (1988), Vallet et al. (1978), and Yeowart et al. (1977)], it is preferred to ask the respondents to give their subjective ratings both for shooting and for road-traffic sounds. Only in studies designed in this way moderating socio-economic and psychological effects will be maximally reduced, yielding a comprehensive estimate of the penalty for shooting sounds.
The latter approach was chosen in our field survey on the annoyance caused by sounds produced by small firearms on the five shooting sites mentioned above (Buchta et al., 1983; Buchta, 1990). The penalty was to some extent dependent on the definition of the annoyance and the definition of the time period for which the Leq of the shooting sounds is computed. At least for relatively low and moderate levels [impulse L_{eq} <52 dB(A)], a typical penalty of about 12-15 dB was obtained.
In the field studies of Sörensen and Magnusson (1979), Bullen and Hede (1982), and Heintz (1980), the dose-response relationships for shooting sounds were not supplemented with comparable relationships for a more continuous reference sound such as road-traffic sound. In a previous review (Vos, 1985), the dose-response relationships of these three studies were related to a dose-response relation for road-traffic sounds that was based on seven surveys that are described in more detail by Schultz (1978). This comparison yielded a mean penalty of 12 dB.
In laboratory studies from a joint project on the effects of impulse sounds on human beings [initiated by the Commission of the European Communities (CEC)], subjects rated the annoyance of road-traffic and gunfire sounds at various levels. The results emphasized the need of a level-dependent penalty: a penalty of about 10 dB at a relatively low indoor L_{eq} of 25-35 dB(A), gradually decreasing by 3 dB for every 10 dB increment in the L_{eq} (e.g., see Flindell and Rice, 1986; Rice, 1983; Vos, 1990; Vos and Smoorenburg, 1985).
One could hypothesize that the coincidence of the dose-response relationships at high L_{eq}-values is at least partly the result of the use of the ten-point rating scale: due to a ceiling effect, subjects could have been restricted to freely express their annoyance caused by the high-level gunfire sounds. By using the methods of adjustment and paired comparison, however, Vos (1990) showed that the level-dependent penalty was not merely a consequence of the use of the rating scale.
In the recent study conducted by Buchta (1993) and Schomer et al. (1992, supported by the Ministry of Defense), the need for a level-dependent penalty was confirmed within six stimulus conditions. In the 60-shots condition the penalty (last columns of Table I) decreased from 12.6 dB at an L_{ASEL} of 50.9 dB to 5.9 dB at an L_{ASEL} of 80.2 dB; in the 6-shots condition the penalty decreased from 12.6 dB at an L_{ASEL} of 42.0 dB to 4.0 dB at an L_{ASEL} of 71.7 dB.

Depending on the level conditions, when the subjects were sitting in rooms with closed windows, opened windows or outside, there is a variation of the penalty from very high penalty at 35 dB L_{Aeq} to smaller penalty at higher and lower levels, as shown in Fig. 2.

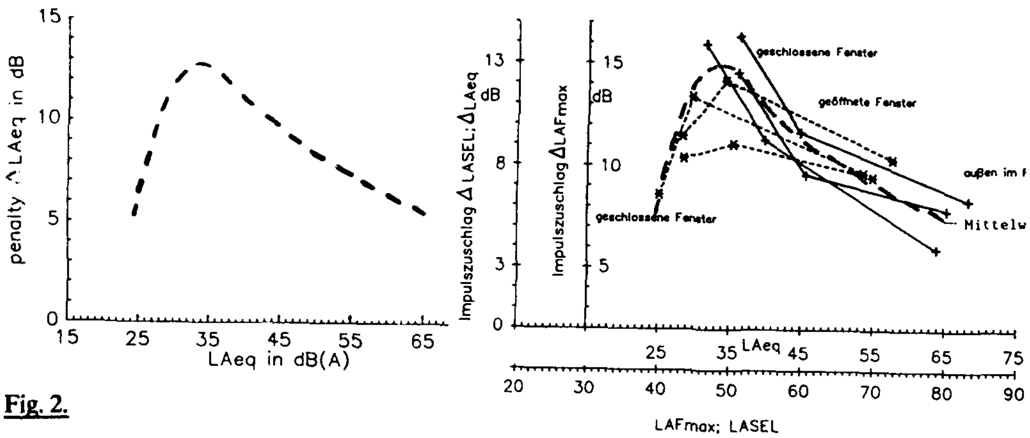

Fig. 2.

Penalty for sounds produced by large firearms

The spectrum of shooting sounds produced by large firearms such as the cannons from tanks and the artillery, is dominated by the energy in low-frequency bands. In contrast with the impulses from small firearms, these artillery sounds can excite noticeable vibration of dwellings. The induced vibration in dwellings generates additional annoyance beyond that due to the audibility of the impulses because of house rattling, startle, and fear for structure damage.

For many years, procedures for the assessment of community response to this kind of high-energy impulse sounds (Galloway, 1981) have been based on the results from two field surveys only: the sonic-boom study in the Oklahoma City area (Borsky, 1965) and a field survey on artillery noise reported by Schomer (1982). On the basis of the results from these two studies, together with additional results from studies on, amongst others, the annoyance of sonic booms relative to that of airplane flyover noise (see Kryter, 1985, Ch. 5), CHABA Working Group 84 (Galloway, 1981) in fact proposed to express the dose of the impulses in the average C-weighted day-night level L_{dn} and concluded that above an L_{dn} of 60 dB(C), the annoyance rises more rapidly than is indicated by a comparable relation between L_{dn} in dB(A) and the annoyance caused by traffic noise.

In the last decade, additional field surveys on the annoyance caused by artillery noise have been carried out by our own institute. The results of these studies will be described. In 1991, about 515 residents from 20 separate noise zones around training fields in the vicinity of Bergen and Munster responded to 4 questions about subjective effects of blast noise and civil road-traffic noise (Buchta, 1993). For the present purpose, the answers to two identical sets of questions will be considered, one set for each sound type. The questions informed about annoyance, satisfaction and loudness with closed and opened windows. For blast noise the C-weighted L_{eq}, and for road-traffic noise the A-weighted L_{eq} was determined.

For blast noise the mean overall score (y) is given by $y = -0.54 + 0.059L_{eq}$, and for road-traffic noise $y = -0.50 + 0.055L_{eq}$, r-values were 0.51 and 0.46, respectively.

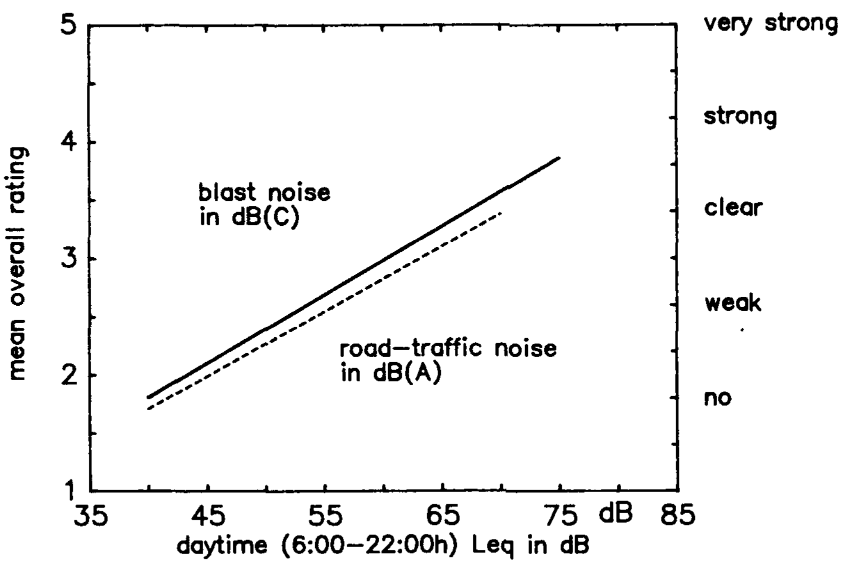

Fig. 3. Mean overall rating as a function of the C-weighted L_{eq} of blast noise and the A-weighted L_{eq} of road-traffic noise.

The two dose-response relationships are given in Fig. 3. The functions almost coincide in the slope. The mean overall score for the shooting sounds was by 2,2 dB significantly higher for $p < 0.005$ than that for the road-traffic sounds.

If we consider the sonic boom data as reported by Schomer (1982, Table A1), the Fort Bragg data on artillery fire (Schomer, 1982), and the data shown in Fig. 4, we conclude that the dose-response relationship for blast noise [with L_{eq} in dB(C)] is shifted to the left by at least 5 dB relative to the relation for road-traffic noise [with L_{eq} in dB(A)]. In one of Schomer's reviews (Schomer, 1985), a comparable conclusion was drawn. It would be interesting to verify whether the functions, as shown in Fig. 3, would also coincide if the effect was expressed in the percentage highly annoyed.

Fig. 4 shows that the slope of the highly annoyed curve for blast noise is higher and also the difference between highly annoyed by blast noise and traffic noise is about 12 dB higher than the mean overall rating.

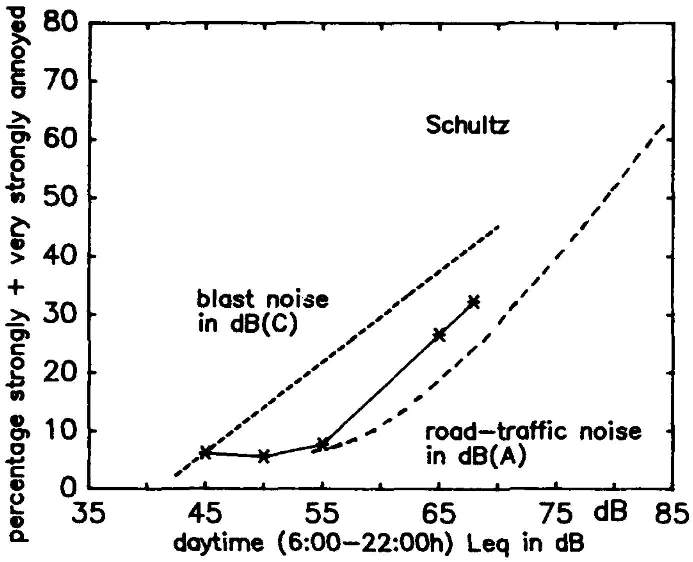

Fig. 4. Percentage highly annoyed as a function of L_{eq} of artillery fire in dB(C). The synthesized curve for road-traffic sounds is given as a reference.

CONCLUSIONS

Results from field and laboratory studies show that for the prediction of annoyance caused by impulse sounds, L_{eq} is superior to measures that ignore the number of acoustic events. This finding is consistent with the predictability of the annoyance caused by road-traffic sounds.

For impulse sounds produced by small firearms at L_{eq}-values of about 35 dB(A) indoor and 50 dB(A) outdoor, a penalty of typically 12 - 13 dB should be added to L_{eq} to obtain the L_{eq} of equally annoying road-traffic sound. The results from laboratory experiments show that a smaller penalty may be applied in conditions with higher impulse levels: the penalty should be level-dependent.

For impulse sounds produced by large firearms, a level-dependent penalty may be needed as well. The application of a penalty cannot simply be avoided by expressing the L_{eq} of the impulses in dB(C) rather than in dB(A).

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RESPONSE FUNCTIONS FOR ENVIRONMENTAL NOISE

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Abstract

Particularly since Schultz (1978) published his single curve as the best currently available estimate of public annoyance due to transportation noise of all kinds, there has been an intense debate about the adequate description of the relation between dose and response for environmental noise. Here results are reported concerning that relation. The results are based on a re-analysis of the compiled original data from a number of dose-response studies.

Dose-response functions are presented for different sources of transportation noise (aircraft, highway, other road traffic, railway) and for stationary sources (impulse noise as well as non-impulse). It was found that, at the same L_{dn}, aircraft noise and highway noise are more annoying than other road traffic noise, which in turn was found to be more annoying than railway noise (trains, trams). Especially at low levels, impulse noise is more annoying than any kind of transportation noise. These results are compared with Schultz' synthesis curve and with the refined description proposed by Kryter (1982).

In a discussion first it is noted that noise limits, contrary to the limits for many other pollutants, do permit the occurrence of considerable adverse effects. Then a system is described for rating adverse effects due to noise immissions. The system is based upon the reported dose-response functions.

Introduction

For a summary of data on the relation between exposure and annoyance from environmental noise, a paper by Schultz and the subsequent discussion between Schultz and Kryter are particulary informative (Schultz, 1978, 1982; Kryter, 1982, 1983). In his 1978 article Schultz discussed a large number of noise annoyance investigations carried out in several countries. These investigations concerned aircraft, railway traffic and various types of road traffic. In order to make the investigations comparable Schultz used the available data to determine the day-night level, L_{dn}. He also attempted to define annoyance in a similar way.

For each of the investigations he drew up a curve showing the percentage highly annoyed persons as a function of the L_{dn} (Schultz, 1978: figure 2). On the basis of the individual curves he synthesized a single curve as the 'best currently available estimate of public annoyance due to transportation noise of all kinds' (Schultz, 1978: figure 3). He also remarked: 'It may also be applicable to community noise of other kinds.'

Kryter (1982) casted doubt on the adequacy of the synthesized curve. He argued that for ground traffic (i.e., road and rail traffic) and air traffic separate and non-identical curves give a significantly better representation of the data considered by Schultz (Kryter, 1982: figure 11). According to Kryter, for a given L_{dn} the annoyance due to aircraft is higher than indicated by the synthesized curve, whereas the annoyance due to ground transportation noise is lower. Kryter pointed out that although the annoyance due to the different sources can indeed be compared, the annoyance caused by different sources is of a different kind. This is shown when the activity disturbance ratings are compared (Kryter, 1982: figure 13).

The discussion between Kryter and Schultz regarding the adequacy of a single curve for transportation noise has not led to agreement between them. Recently, Fidell, Barber and Schultz (1991) extended the original compilation of Schultz and arrived at the same curve. Although their additional data appear to support Kryter's point that at the same exposure level aircraft noise is more annoying than ground transportation noise, the authors ignored the discussion with Kryter in which this point

was brought forward.
The debate between Schultz and Kryter also has been joined by others and there has been a continuing interest in this subject. After a description of a compilation of data, some results based on a re-analysis of these data are presented. Then a rating of noise immissions, based on these results, will be discussed.

The coı. ·d data

The following original data were compiled for re-analyses.
For *aircraft* noise three coordinated investigations (see, e.g., Diamond and Walker, 1986; total N = 1758) were included in the compilation. They have been carried out, in 1984, in France around Paris-Orly, in the Netherlands around Amsterdam-Schiphol and in the United Kingdom around Glasgow(-Abbotsinch) Airport.
For *railway* noise four studies were included. The first is a railway study (see Fields and Walker, 1980; N = 1453) that was carried out in 1975/76 at 75 locations all over Great Britain. The second is a Netherlands' railway study (see Peeters et al., 1984; N = 671), carried out in 1977 at 9 different locations. This and the British study only concerned trains. The third is a German study (see Schümer-Kohrs et al., 1983; N = 1651) carried out in 1978/81 at 22 location all over the former West-Germany. At most locations the persons were exposed to noise from trains, at 2 locations the railway noise was caused by trams. The fourth is a Netherlands' study (see Miedema, 1985; N = 739) carried out in 1983 at a number of locations in three cities, where people were exposed to the noise from trams.
For *road traffic* the following studies were included. Two similar investigations (see Bitter et al., 1978; Bitter et al., 1982; total N = 1058) that were carried out in 1974 and in 1975, respectively, near two different highways in the Netherlands. A road traffic study (see Ericz et. al., 1986; N = 300) carried out in one city in the Netherlands. And the following above mentioned studies, which also concerned road traffic noise. The three coordinated investigations (N = 1758), the German study (N = 1651) and the study carried out in three cities in the Netherlands (N = 739).
For noise from *stationary sources* four coordinated investigations were included, that have been carried out in 1982/83 at a number of locations in France, Germany, the Netherlands and Ireland (see, e.g., Groeneveld and De Jong, 1985; total N = 1458). They concerned impulse noise and the noise from shunting yards. In addition a study (see Groeneveld and Gerretsen, 1984; N = 597) was incorporated that was carried out in 1984 and was concerned with industrial noise and the noise from shunting yards.

The analyses

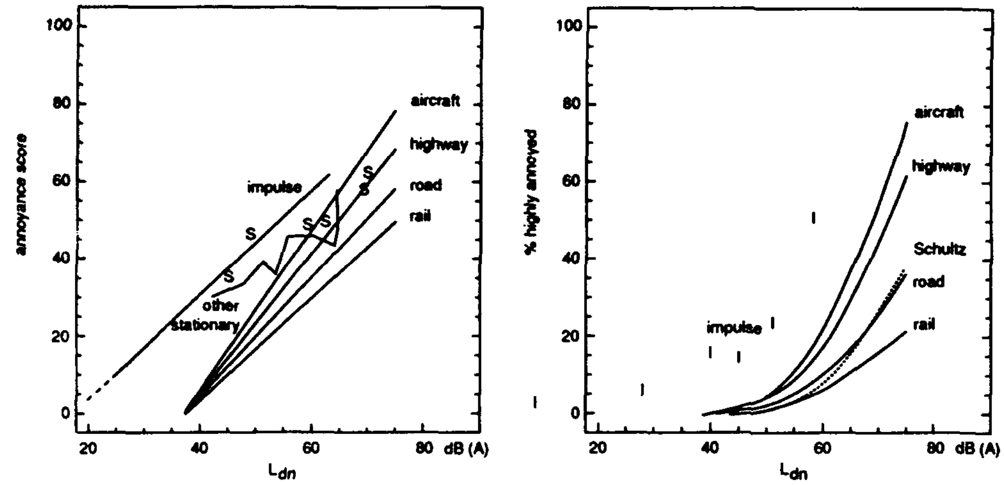
To find the response functions, the compiled original data were re-analyzed at the individual level. Much effort has been put into a comparable determination of the exposure measures and the effect measures for the cases from different studies. An extensive description of the determination of these measures on the basis of the data available is given by Miedema (1992). Here we will only sketch some aspects of the approach taken.
For the *dose* the L_{Aeq}(24h), L_{dn} en L_{etm} were determined. The L_{etm} is used in the Netherlands' legislation and is defined as the maximum of L_{Aeq}(7-19), L_{Aeq}(19-23) + 5 and L_{Aeq}(23-7) + 10. The three measures, L_{Aeq}(24h), L_{dn} en L_{etm}, can be calculated if the L_{Aeq}'s are known for the periods 7-19h, 19-22h, 22-23h and 23-7h or for subdivisions of these periods.
All studies in the compilation contained data on L_{Aeq}'s and many of the required L_{Aeq}'s could be determined directly. Sometimes an estimation was necessary, e.g., if only the L_{Aeq}(6-22) and L_{Aeq}(22-6) were contained in a data set. In those cases we used additional information, about the numbers of passages per hour (e.g., for trains) or on the operation time of the source (e.g., for industry), which was available in the research reports. By combining this information with the L_{Aeq}'s

that were given, the required L_{Aeq}'s were estimated.
We also gave attention to the way in which the L_{Aeq}'s in the studies were determined. For instance, in some studies L_{Aeq}'s were used as they were measured in front of a facade, including the contributions from the sound reflected by that facade. In most studies, on the other hand, the L_{Aeq}'s pertain to the direct sound, without contributions from reflections. In the cases, where reflections were included, we used data about the contributions from the reflections to correct the L_{Aeq}'s that were given. In that way we took care that all L_{Aeq}'s pertained to the direct sound immission, without reflections.
Here we will only report about the annoyance *response* that is determined by the following kind of question, which does not refer to any specific kind of interference which the noise may cause: "How much would you say that the noise from ... annoys you?". For an answer a person could, e.g., choose between 'not at all', 'a little', 'moderately' or 'very much'.
Two methods have been used for summarizing the data about the dose-response combinations, found per person, by *dose-response* functions. The resulting functions are alternative ways of representing the same data.
One method first assigns scores to the (midpoints of the) annoyance categories. In general the following rule is used to assign scores to categories: (score for category i) = 100 (i-½) / m, where m is the number of categories and i, i = 1,...,m, is the rank number for a category (1 for the least annoyance, m for the highest annoyance). Then a best fitting curve is sought that summarizes all pairs consisting of a dose measure value and an annoyance score.
Another method assigns, in a similar way, scores to the boundaries between the annoyance categories, according to the following rule: (score for interior boundary i) = 100 i / m, where m is the number of categories and i, i = 1,...,m-1 is the rank number of the interior boundaries between categories, starting at low annoyance. Then, per exposure class, the percentage of respondents is determined, who chose an annoyance category above a certain boundary. Percentages obtained by using 28, 50 and 72 as boundary are called the percentages of the respondents that are 'at least moderately annoyed', 'annoyed' and 'highly annoyed' respectively. These boundaries do not always correspond to the boundaries between the annoyance categories used in a particular study. Therefore, interpolations have been carried out. For example, according to the above rule the interior boundaries between five categories are: 20, 40, 60 and 80. The percentage 'annoyed' is defined as the percentage of respondents who chose an annoyance category above boundary 50. This percentage is determined by linear interpolation $(P_{40} + P_{60}) / 2$, where P_{40} and P_{60} are the percentages of respondents who came into the three and two highest categories respectively.
The procedures for scoring the midpoints and the boundaries of annoyance categories has been tested by using data from the three coordinated investigations concerning aircraft noise and the four coordinated investigations concerning impulse and shunting noise, which employed both an annoyance question with four and one with ten answer categories. By a so-called correspondence analysis (see, e.g., Greenacre, 1984) the annoyance categories were scored so that each person has as much as possible, in a statistical sense, the same score on both questions. Miedema (1992: figures 4.3 and 4.21) shows that the optimal scores (assigned in this way) roughly are a linear function of the scores assigned by the above rule for the midpoints. This supports the usage of the above given, related rules for the assignment of scores to the midpoints and the boundaries of the categories.

The dose-response functions

Figure 1 shows for different modes of transportation noise (aircraft, highway, other road traffic, railway; overall correlation r = .50) and for stationary impulse noise sources (r = .48) the annoyance score as a function of the L_{dn}. The curve for non-impulse industrial noise sources is determined by interpolation between the data for relatively few locations, after some outliers have been removed. Hence no correlation is given. The points marked by 'S' represent results concerning stationary

Figures 1 and 2. The annoyance score (fig. 1: left) and the percentage highly annoyed (fig.2: right) as a function of the L_{dn}.



sources from a study by Finke et al. (1980). For this study we did not have the original data. Since we had relatively few data on this kind of sources and since we were able to derive from the research reports percentages highly annoyed conforming to our above definition, we include these results in the figure.

Figure 2 presents for the transportation noise sources the percentage highly annoyed as a function of the L_{dn}, together with Schultz' synthesis curve.

Both figures demonstrate that, at the same L_{dn}, aircraft and highway noise are more annoying than other road traffic noise, which in turn is more annoying than railway noise (trains, trams). The impulse noise level at which people start to report annoyance is considerably lower than the 'annoyance threshold' for transportation sources and, especially at low levels, impulse noise is more annoying than any transportation noise.

These results can be related to the discussion concerning Schultz' synthesis curve. Our curve for the percentage highly annoyed for road traffic (not highway) approximately coincides with Schultz' curve. Our finding that the curve for aircraft lies above the road traffic curve, which in turn lies above the curve for railway noise ('above' means more highly annoyed at the same L_{dn}) supports the conclusion of Kryter (1982) that, at the same L_{dn}, aircraft noise is more annoying than noise from ground vehicles. Kryter argued that this conclusion was already suggested by the data considered by Schultz. But for highway noise we found a curve for the percentage highly annoyed that is close the curve for aircraft noise. Furthermore, we did not find a single curve for all kinds of ground vehicle noise, but separate curves for highway noise, other road traffic noise and railway noise. For impulse noise a relation with the L_{dn} was found that is different from the relations for transportation noise.

All together it appears that neither a single curve (Schultz) nor two separate curves (Kryter), for aircraft and ground vehicles, suffice to give an adequate representation of the data for *transportation* noise. The straight line, relating for *stationary impulse* noise the annoyance score to the L_{dn}, shows that, especially at lower levels, impulse noise causes more annoyance than any kind of transportation noise. For *other stationary* industrial sources, no clear relation with the exposure was found, but the annoyance score exceeded at nearly all L_{dn} levels the annoyance score for highway noise.

Discussion

Based upon their effect on humans, environmental factors can be subdivided into two categories. Some factors, such as toxic or carcinogenic substances and radiation, are considered to be a problem because of their potential influence on the somatic health condition. Other factors, such as noise and odour, are considered to constitute an environmental problem mainly because they are perceived by humans and because of the negative appraisal of this perception. The factors in the former category can be called 'somatic' and those in the latter 'perceptual'. Of course, some factors may cause both kinds of effects.

In many countries the aim of environmental regulations for somatic factors is to prevent the occurrence of adverse effects. For example, in the Netherlands the *maximum* concentration for toxic subtances, which have a threshold level below which adverse effects do not occur, is set at or below that threshold. The concentration that is considered to be *negligible* still is considerably lower, namely 1% of the maximally allowed concentration.

We are not aware of regulations in any country which, when fully implemented, would prevent adverse effects of perceptual factors from occurring. Instead the aim for these factors is to limit the occurrence of strong effects. So, there appears to be a discrepancy between the goals set for somatic and for perceptual factors, which might be an interesting point of discussion for the ICBEN team concerned with the community response to noise and the team concerned with regulations and standards.

To get a clear view on the adverse effects of environmental noise, dose-response function are very important. These response functions, which relate the strength of the effects to the exposure, are needed for the formulation of consistent health limits.

In order to give a concise indication about the consequences of noise immissions, we have proposed a rating system in terms of the L_{etm} (Miedema, 1992). The boundaries for L_{dn} classes are 2 to 3 dB(A) lower. Of course, discussion is possible about the formulation of the labels for the classes. But the correspondence between the class boundaries for different sources is an empirical matter and is based on the above reported relations between the annoyance scores and the L_{dn}.

rating	L_{dn} other road	highway	aircraft	railway	impulse	non-imp industry
good	< 37	< 37	< 37	< 37	< 15	< 37
rather good	37-43	37-42	37-41	37-44	15-22	37-42
reasonable	43-48	42-46	41-45	44-50	22-28	42-46
moderate	48-53	46-51	45-49	50-56	28-34	46-51
rather bad	53-58	51-55	49-52	56-62	34-39	51-55
bad	58-63	55-59	52-56	62-67	39-45	55-59
very bad	63-68	59-63	56-60	67-73	45-51	59-63
extremely bad	≥ 68	≥ 63	≥ 60	≥ 73	≥ 51	≥ 63

The motivation for the quality labels is as follows. A situation with exposure to road traffic noise (not highway) is considered to be 'good' up to the level where annoyance starts (road traffic L_{dn} = 37 dB(A)). When nearly one third (30%) is negatively affected in the sense that they report at least moderate annoyance, ten percent is annoyed and some persons are highly annoyed, we do not longer call a situation rather good or reasonable but start calling it 'moderate' (road traffic L_{dn} = 48 dB(A)). At the point where the majority of the population becomes at least moderately annoyed, a quarter is annoyed and five to ten percent is highly annoyed we start calling a situation 'bad' (road traffic L_{dn} = 58 dB(A)) When the large majority (two thirds) is negatively affected in the sense that they report at least moderate annoyance, between 40 and 50% is annoyed and between 20 and 25% is highly annoyed, we start calling a situation 'extremely bad' (road traffic L_{dn} = 68 dB(A)).

We have noted that the annoyance score for non-impulsive industrial noise nearly always exceeds

the annoyance score for highway noise. Therefore, the annoyance level for highway noise has been taken as a lower boundary for the heterogeneous set of non-impulsive industrial sources and has been used to determine the boundaries for the right column.
It should be noted that special features are not taken into account in the above rating system. For example, incidental sounds of an industry or the squealing of a tram may cause a higher annoyance than would be expected on the basis of the dose-response curves that we have presented here and on which the above rating system is based.

We are well aware that also the synthesis curves presented here leave some questions unanswered. We plan to work on these questions, extend the compilation on which the synthesis is based and we will try to establish curves on an increasingly solid basis. But the existing knowledge about noise annoyance is already relatively extensive and can be used, e.g., for setting health limits with respect to noise. It may be noted that for somatic factors much more stringent limits than for noise are widely accepted and used, often on the basis of much weaker evidence about their effects than is available for noise.

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THE SOCIAL IMPACT OF NOISE PREVENTION AND REDUCTION MEASURES

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Abstract

Noise prevention and reduction measures have not only had a significant effect on reducing noise levels but an extremely significant social impact. If the primary effect sought is to reduce overall or behavioural annoyance and the disturbance to domestic activities, positive and negative induced or secondary effects can also be observed. The wide diversity of effects raises questions about the methods used to evaluate the effectiveness of noise abatement prevention and reduction measures. A research programme could be of interest as it would provide pertinent and complete information for decision-makers.

Résumé

Les conséquences de la mise en oeuvre des mesures de protection contre le bruit sont très nombreuses. Outre le fait de limiter ou réduire les niveaux sonores, ces mesures ont un impact social très important. Les enquêtes concernant la perception et la satisfaction de populations protégées du bruit révèlent en effet une grande diversité des effets et donc des bénéfices que la collectivité peut retirer de la mise en oeuvre de ces mesures. Parallèlement à une limitation ou une réduction de la gêne globale ou comportementale ainsi que des activités perturbées au domicile, on observe également de multiples effets secondaires ou induits, positifs ou négatifs de nature très différente. Cette multiplicité des effets conduit à s'interroger sur la méthode d'évaluation de l'efficacité des mesures de protection contre le bruit. L'approche unicritère en termes de "gains acoustiques prévisibles - variation du niveau de gêne" qui apparaît très réductrice, pourrait évoluer vers une approche multicritère et donc plus extensive de l'évaluation de ces impacts. Des travaux de recherche mériteraient d'être entrepris dans cette direction afin que les décideurs puissent disposer d'une information aussi pertinente et complète que possible pour éclairer leurs choix.

I - INTRODUCTION

For almost 15 years a large number of industrialised nations have been applying regulations or legislation which aim to protect populations from noise when new transportation infrastructures are created [1]. Depending on the country concerned, the maximum authorised daytime Leq is usually in the 60 to 65 dB(A) range. Guidelines for "blackspot" correction usually consider that action should be taken when the daytime Leq exceeds 70 dB(A).

Initially, the situations adopted consisted in erecting noise barriers along roads and railway lines in suburbs and rural areas. In urban environments the most frequently used solution was to soundproof the facades of highly exposed buildings. More recent measures include low-noise road surfaces and traffic control techniques.

These solutions have not only reduced noise levels but have had an extremely significant social impact. Social surveys of the perceptions and satisfaction levels of populations protected from noise reveal a wide range of both positive and negative impacts.

II - THE IMPACT OF NOISE BARRIERS

Much research has been carried out over the last 20 years to assess the effectiveness of noise barriers by studying the perceptions and attitudes of the residents concerned [2 to 7].

Noise barriers protect dwellings closest to roads and reduce noise levels by amounts between 3 to 12 dB(A) at distances from 10 to 100 metres. Attenuation is highest in the 800 to 8000 Hz range and at 150 metres there is no reduction in noise whatsoever. It is only possible to use this type of barrier in suburban and rural zones traversed by trunk roads and motorways.

What impact is observed when noise barriers of this type are erected ?

Firstly, a reduction in total annoyance : the average annoyance level or percentage of people who are annoyed or highly annoyed decreases. For example, in Australia [6], the use of noise barriers along the Berowra-Wahroonga motorway (F3) reduced the percentage of people who were very annoyed by noise from 42 to 17%.

In a recent study in France [7], the percentage of people who were excessively annoyed by noise decreased from 24 to 17%. For an identical reduction in noise levels, the decrease in noise annoyance seems to be more significant when the initial noise level is higher than 63 dB(A).

As annoyance falls, there is also a decrease in the number of activities affected by noise. People sleep better, spend more time reading, extend their leisure time and use their gardens and balconies more frequently (Table 1).

Table 1. Noise levels, annoyance, activities affected and changes in behaviour patterns due to the erection of noise barriers [7]

INDICATORS	BEFORE	AFTER
LAeq (8 a.m. - 8 p.m.)	65.1	56.6
Annoyance level (5-point-scale)	3.3	3.0
Excessively annoyed	23.7 %	17.1 %
Affected when reading and writing	19.7 %	11.8 %
Disturbed sleep	18.4 %	10.5 %
Restricted use of garden and balcony	31.6 %	18.4 %
Turn up TV volume	22.3 %	11.8 %
Close windows	48.7 %	34.2 %

Although the average level of annoyance does not decrease significantly, the other indicators vary in a significant way and demonstrate the effectiveness of noise barriers. Depending on the surveys, this effectiveness is acknowledged by 60 to 70 % of the residents concerned (Table 2).

Table 2. Percentage of people who find noise barriers effective

SURVEYS	%
A. Hall (1986) [4]	62
M. Cooper (1988) [5]	59
Geoplan (1992) [6]	60
I. Vernet et al. (1992) [7]	68
J. Lambert et al. (1992) [8]	66

Secondary effects observed in studies on local residents related to the erection of noise barriers include :

- a feeling of greater protection from the road ;
- the emergence of other noise sources, particularly from the immediate neighbourhood.

Quite frequently the appearance of noise barriers causes a negative response, particularly in rural areas ; embankments are generally preferred as they integrate more easily into the landscape [4, 8]. However, in both cases, local residents often mention visual intrusion.

Over and above the short-term impact following the erection of noise barriers, it is also interesting to consider how annoyance levels change in subsequent years [9].

III - THE IMPACT OF THE INSULATION OF DWELLINGS

Usually the only viable technical solution enabling noise exposure levels inside dwellings in city centres to be restricted is soundproofing. The following example from the Lyon region in France is a good illustration of the diversity of positive and negative effects directly due to this type of protection.

A total of 2 300 flats in the Bron-Parilly suburb of Lyon were soundproofed between 1980 and 1982. This vast corrective operation included double glazing of the existing windows. An insulation level of 42 dB(A) was attained vs. 19 to 21 dB(A) prior to the works, i.e. an extra 21 to 23 dB(A) of insulation was gained by soundproofing. Noise levels on the facades of these dwellings were in the 70 to 75 dB(A) range (LAeq 8 a.m. - 8 p.m.) for average traffic densities of 90 000 to 100 000 vehicles per day, 8% of which were heavy goods vehicles.

Two studies were carried out on the residents of the buildings :

- a "Before and After" survey of 100 people a few months before and a few months after the soundproofing works [10] ;
- an "After" survey of 300 people 3 to 5 years after the dwellings were soundproofed [11].

Both studies demonstrated the following impact categories :

- positive impacts directly related to the reduction of sound levels and positive indirect impacts related to the soundproofing of the dwellings but not to a reduction in noise levels ;
- negative direct and indirect impacts.

The main positive impacts included :

- a significant reduction in annoyance levels when windows are closed, particularly at night ;
- a significant improvement in sleeping conditions with a steep reduction - from 21 to 9 per flat - in the average number of awakenings and temporal reactions during the night and an improvement in the daytime with an increase in leisure time in the home (+20% in the sitting room) and an increase in the frequency of visits by family and friends (+55%) ;
- 45 % of the population mentioned a decrease in pollution from the outside (in particular from dust) ;
- a decrease in heating expenses because thermal insulation was also improved.

Negative impacts included :

- the continuing necessity to keep windows closed so as not to be disturbed : 80% of the residents questioned still declared themselves to be annoyed or highly annoyed when the windows were open ;

- the emergence of noise inside dwellings, particularly noises from neighbours, to a significant extent (+ 53 %) but also new nuisances which until then had been "masked" by noise (including smells) ;

- the appearance of double glazing as seen from indoors ; this is contested by 41% of the residents and seems to have a relationship with the "After" annoyance level ;

- the fact that outdoor spaces related to the dwellings were not protected (relaxation areas, leisure areas and meeting places) ; these were under-used, poorly maintained and in some cases completely abandoned.

IV - THE IMPACT OF LOW NOISE ROAD SURFACES

Up until now little research has evaluated the impact of low noise road surfaces on local urban populations. Some results are however available for France concerning Paris and Nantes where a psycho-sociological "Before and After" survey was carried out in 1989 [12].

The reduction in noise levels (expressed in LAeq) achieved 0.5 to 4.5 dB(A), depending on the measurement points and the time of day (Table 3).

Table 3. Decrease in noise levels following the laying of low noise road surfaces

PERIOD	PARIS		NANTES		
	Site 1	Site 2	Site 3	Site 4	Site 5
8 a.m. - 8 p.m.	2.9	2.8	2.1	3.7	4.0
8 p.m. - midnight	3.9	4.2	1.7	3.1	1.7
midnight - 5 a.m.	3.7	4.4	0.4	2.9	1.0
5 a.m. - 8 a.m.	2.4	3.1	1.6	2.9	2.2

Following these reductions in noise levels, the survey carried out on the population showed that :

1. A significant proportion (48%) of the population believed that due to the new road surface the street was quieter than before.

2. Almost one person in two (45%) estimated that the nature of the noise had changed ; most of these (62%) thought that the noise had a deeper tone.

3. There was a relatively low change in the average annoyance levels (Table 4), except site 2 in Paris which initially was particularly noisy because of the cobbled road surface (the daytime noise level was higher than 73 dB(A)). Concurrently with a decrease of over 4 dB(A) in noise levels during the evening and particularly during the night at this site, an extremely significant improvement was noted in the quality of residents' sleep.

Table 4. Average "Before and After" noise annoyance levels following the laying of the low noise road surfaces

SURVEY SITES	AVERAGE ANNOYANCE LEVEL (7 point-scale)		
	Before	After	Difference
Site 1	3.6	3.4	- 0.2
Site 2	4.4	3.3	- 1.1
Site 3 to 5	4.1	4.2	+ 0.1

For Nantes (sites 3 to 5), there was a negligible difference between "Before" and "After" annoyance levels. However, when asked a retrospective question in the "After" survey, 54% of the respondents stated that they were less annoyed "After" than "Before".

4. A total of 19% of the whole population surveyed stated that they were sleeping better (30% for site 2 in Paris), although overall they said that the noise at night still woke them up as much as before.

5. A total of 30% of the sample population considered that the quality of the district had improved. However, the relationship between noise and annoyance levels is not very significant. One possible hypothesis is that to obtain a significant decrease in annoyance levels, as observed in Paris site 2, a minimum reduction in noise levels is necessary particularly during the evening and at night. This means that the factor which mainly influences local residential satisfaction is evening and night time noise exposure.

V - THE IMPACT OF TRAFFIC CONTROL TECHNIQUES

It is possible to reduce noise annoyance and more generally the effects of noise by using traffic control measures such as :

- re-routing "through" traffic (and more particularly heavy goods traffic) to by-passes located outside the town ;

- reducing speeds in residential areas (Tempo 30 in Germany, Zone 30 in France) ;

- generally restricting or moderating traffic in urban areas.

Although such measures are not directly introduced to reduce noise but to reduce traffic jams or to improve road safety, they nevertheless do have an impact on urban noise levels. However, very few surveys have tried to assess the impact of these measures on residents [13 - 14].

J. Kastka surveyed 1700 residents in Germany [15] and showed that a reduction of approximately 1 dB(A) in Leq between 6 a.m. and 10 p.m. produced a significant decrease in annoyance levels. This positive effect corresponds to a theoretical reduction in noise levels from 6 to 14 dB(A). It would appear that, for an identical reduction in noise levels, the reduction of traffic volume has more significant effects on annoyance level than other types of measures such as the erection of noise barriers or soundproofing dwellings.

A very recent "Before - After" survey concerning a by-pass in a small town in France [16] gives a good idea of the diversity of the effects obtained by measures of this kind.

Where traffic had been reduced the most, in the centre of this town, the noise environment changed radically. Initially, extremely high noise levels (LAeq 8 a.m. - 8 p.m. > 70 dB(A)) observed in the main street decreased by 3 to 7 dB(A) due principally to the reduction in the number of heavy goods vehicles. Average annoyance level decreased significantly as well as the percentage of very or excessively annoyed people (Table 5).

Table 5. Noise annoyance level before and after the by-pass

ANNOYANCE LEVEL	BEFORE	AFTER
1 : not annoyed	5.7%	15.7%
2 : slightly annoyed	10.0%	21.4%
3 : annoyed	17.2%	45.7%
4 : very annoyed	17.2%	11.4%
5 : excessively annoyed	50.0%	5.7%
Average annoyance level	4.0	2.7

The positive impact of the by-pass on annoyance is confirmed by the way some domestic activities were affected (Table 6).

Table 6. Activities frequently affected and behaviour patterns before and after the by-pass

	BEFORE	AFTER
Jump	11.4%	1.4%
Conversation	22.8%	8.5%
TV watching	42.9%	21.1%
Reading, writing	17.2%	2.8%
Going to sleep at night	20.0%	2.8%
Waking up in the morning	15.7%	2.9%
Unused bedroom	20.0%	7.0%
Close windows	71.4%	43.6%

Conversely, although mentioned just as frequently in the "Before" and "After" studies, perceived neighbourhood noise was felt to be more of a nuisance after the by-pass was built.

Furthermore, fewer residents (47% prior to the by-pass, 10% after the by-pass was built) would envisage moving away from their district. They consider that the quality of life in their district has significantly improved and that the main street which runs through the town is not only quieter but also safer, cleaner and easier to cross than before.

As for the people who live close to the by-pass (a motorway), the change is reversed but to a lesser extent :

- noise levels, although remaining low (LAeq 8 a.m. - 8 p.m. = 50 to 55 dB(A) after the opening of the by-pass), increased from 4 to 8 dB(A) due primarily to the high volume of heavy goods traffic.

- the average noise annoyance level changed from 1.7 to 2.9 (5-point scale) ; the percentage of people very annoyed or excessively annoyed by road noise increased by a factor of 2.3 ; noise was considered to be unacceptable by over 70% of the people questioned.

- although the frequency of the activities affected did not vary significantly - it should be remembered that their exposure to noise was not excessively high - some indicators show that behaviour patterns have changed although they have not reached levels encountered in areas with high noise levels (Table 7).

Table 7. Behaviours influenced by noise along the by-pass ("often" or "sometimes")

	BEFORE	AFTER
Close windows	46.7 %	61.6 %
Restricted use of the gardens or the balconies	16.7 %	24.0 %
Unused bedroom	6.7 %	21.6 %
Intention to move	6.6 %	21.2 %

VI - WHAT HAVE WE LEARNT FROM THE EFFECTS OF NOISE CONTROL MEASURES ?

The primary effect sought is to reduce overall or behavioural annoyance and thus reduce the disturbance to domestic activities such as sleep, watching TV, conversation etc. The effect of corrective action does, however, depend on a wide range of parameters which are either directly related to noise (decrease in noise levels, modification of the frequency spectrum) or to psycho-sociological factors.

Positive induced or secondary effects have been also observed, for example, the reuse and thus the increase in value of housing and adjacent outdoor spaces - gardens, playgrounds and leisure areas - the revitalization of social relationships between the inhabitants in protected zones, the reduction in air pollution and dust entering the homes from outdoors and energy savings (in the case of improved soundproofing), a feeling of enhanced security when a noise barrier is located between buildings and roadways or in the case of by-pass.

These positive effects could be nevertheless counterbalanced by negative induced effects such as emergence of noise from other sources which had previously been hidden (in particular noise from neighbours inside and outside buildings), the lack of soundproofing of outdoor spaces when homes have been insulated, the visual intrusion and the appearance of noise barriers, particularly in rural areas.

This wide diversity of effects raises questions about the methods used to evaluate the effectiveness of noise abatement prevention and reduction measures. The somewhat limited single criterion approach in terms of "forecast noise level reductions - change in the annoyance level" should now be extend to a multi-criteria approach to evaluate these effects. This new approach can be particularly effective in situations in which there is a significant decrease in annoyance due to a relatively small decrease in noise levels.

A research programme to investigate and develop this approach could be of interest as it would provide pertinent and complete information for decision-makers.

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L'IMPACT SOCIAL DES MESURES DE PREVENTION ET DE REDUCTION DU BRUIT

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I - INTRODUCTION

Depuis près de 15 ans un grand nombre de pays industrialisés appliquent des réglementations visant à protéger les populations contre les nuisances sonores que ce soit dans le cadre de création d'infrastructures nouvelles de transport [1], lorsque le Leq de jour est, suivant le pays concerné, compris entre 60 et 65 dB(A) ou lors d'opérations de rattrapage de situations critiques d'exposition au bruit, le plus souvent lorsque le Leq est supérieur à 70 dB(A).

Dans un premier temps les solutions retenues ont consisté à mettre en place des écrans phoniques ainsi que des buttes de terre le long des voies routières et ferroviaires situées en périphérie des villes ou en zone rurale ; pour le milieu urbain on a recouru largement à l'isolation de façade des bâtiments les plus exposés. Plus récemment d'autres mesures sont venues compléter cet arsenal technique comme l'utilisation de chaussées peu bruyantes et la limitation des vitesses de circulation (Tempo 30 en Allemagne, Zone 30 en France par exemple).

Les conséquences de la mise en oeuvre de ces mesures sont très nombreuses. Outre le fait de limiter ou réduire les niveaux sonores, ces mesures ont un impact social très important. Les enquêtes concernant la perception et la satisfaction de populations protégées contre le bruit révèlent en effet une grande diversité des impacts

II - IMPACT DES ECRANS ACOUSTIQUES

De nombreuses recherches ont été menées depuis près de 20 ans pour évaluer l'efficacité des écrans acoustiques en termes d'opinion ou d'attitudes des résidents concernés [2 à 7].

Les écrans, les buttes de terre permettent, pour les habitations les plus proches de la voie, des gains acoustiques de 3 à 10 dB(A) entre 10 et 100 mètres, et de très fortes atténuations sont mesurées entre 800 et 8000 Hz. Au-delà de 150 mètres les gains acoustiques sont nuls. L'utilisation de ces protections n'est cependant possible qu'en zone périurbaine ou rurale traversée par des voies nationales ou autoroutières.

A quels impacts conduit la mise en place de ce type de protection ?

Tout d'abord une réduction de la gêne globale (diminution de la note moyenne de gêne ou du % de personnes gênées ou très gênées). Par exemple, en Australie [6], la mise en place d'écrans phoniques le long de l'autoroute Berowra-Wahroonga (F3) a permis de réduire le nombre de personnes très gênées par le bruit de 42 à 17 %.

En France, dans une étude récente [7], ce nombre est passé de 24 à 17 %. La diminution de la gêne semble, pour une réduction identique des niveaux sonores, plus importante lorsque le niveau initial de bruit est supérieur à 63 dB(A).

Parallèlement à la réduction de la gêne, on observe une diminution du nombre d'activités perturbées par le bruit qui conduit par exemple à un meilleur sommeil, à une augmentation des temps de détente, à une utilisation plus fréquente des jardins (Tableau 1).

Tableau 1. Niveaux sonores, gêne, activités perturbées et comportements avant-après écrans acoustiques [7]

INDICATEURS	AVANT	APRES
LAeq (8h - 20h)	65,1	56,6
Niveau de gêne (note/5)	3,3	3,0
Excessivement gêné	23,7 %	17,1 %
Est gêné dans la lecture, l'écriture	19,7 %	11,8 %
A son sommeil perturbé	18,4 %	10,5 %
Limite l'utilisation du jardin, du balcon	31,6 %	18,4 %
Est obligé de monter le son de la TV	22,3 %	11,8 %
Ferme ses fenêtres	48,7 %	34,2 %

Bien que le niveau moyen de gêne ne baisse pas sensiblement, les autres indicateurs varient de façon significative et traduisent bien l'efficacité importante des écrans. Cette efficacité est reconnue, suivant les études, par 60 à 70 % des riverains concernés (Tableau 2).

Tableau 2. Pourcentage de personnes trouvant l'écran efficace

Etudes	%
A. Hall (1986) [4]	62
M. Cooper (1988) [5]	59
Geoplan (1992) [6]	60
I. Vernet et al. (1992) [7]	68
J. Lambert et al. (1992) [8]	66

Parmi les effets secondaires liés à la mise en place des écrans on observe souvent dans les enquêtes auprès des riverains :

- un sentiment de plus grande sécurité par rapport à la voie routière ;
- mais aussi l'émergence d'autres sources de bruit, notamment de voisinage.

Parfois l'esthétique de l'écran est contestée, notamment lorsqu'il est implanté en zone rurale ; alors que la butte de terre y est beaucoup plus appréciée car mieux intégrée dans le paysage [4 et 8]. Mais dans les deux cas l'intrusion visuelle est souvent signalée.

Au-delà de ces impacts à court terme, on peut se demander comment évolue la gêne plusieurs années après la mise en place des écrans phoniques [9].

III - IMPACT DE L'INSONORISATION DES LOGEMENTS

L'insonorisation des logements constitue bien souvent la seule solution technique permettant de limiter les niveaux d'exposition au bruit à l'intérieur des logements, en particulier dans les centres-villes. L'exemple suivant, pris en région lyonnaise, illustre parfaitement la multiplicité des effets tant positifs que négatifs de la mise en oeuvre de ce type de protection.

Entre 1980 et 1982, 2 300 logements du quartier de Bron-Parilly (situé dans la banlieue de Lyon) ont

été insonorisés. Cette vaste opération de rattrapage a conduit à traiter les façades par doublage des panneaux existants. Un niveau d'isolation de 42 dB(A) a ainsi été atteint contre 19 à 21 dB(A) avant travaux, soit une isolation supplémentaire de 21 à 23 dB(A). Les niveaux sonores en façade d'habitation se situaient entre 70 et 75 dB(A) (LAeq 8h-20h) pour des trafics moyens journaliers de 90 000 à 100 000 véhicules (8 % de poids lourds).

Deux enquêtes auprès des résidents des immeubles ont été menées :

- une enquête "Avant-Après" auprès de 100 personnes, quelques mois avant et quelques mois après les travaux d'insonorisation [10] ;

- une enquête "Après" auprès de 300 personnes, 3 à 5 ans après les travaux d'insonorisation des logements [11].

Ces deux enquêtes ont mis en évidence quatre catégories d'impact :

- des impacts positifs directs (liés à la réduction des niveaux sonores) et induits (liés à l'insonorisation des logements mais pas à la réduction des niveaux sonores) ;

- des impacts négatifs directs et induits.

Parmi les principaux impacts positifs on peut citer :

- une diminution importante de la gêne, fenêtres fermées, principalement la nuit (amélioration sensible des conditions de sommeil : baisse de 21 à 9 du nombre moyen de réveils et de réactions temporelles par nuit) mais aussi le jour (accroissement des moments de détente au domicile (+20% dans le séjour) et de la fréquence des visites de la famille et des amis (+ 55 %)) ;

- une diminution de la pollution en provenance de l'extérieur (poussières en particulier pour 45 % des personnes) ; une diminution des dépenses de chauffage (l'isolation thermique étant également améliorée).

Parmi les impacts négatifs on trouve :

- l'obligation de vivre fenêtres fermées pour ne plus être gêné (80 % des résidents interrogés se déclarent encore gênés ou très gênés lorsque les fenêtres sont ouvertes) ;

- l'émergence de bruits internes à l'habitat (bruit des voisins notamment) dans une proportion importante (+ 53 %) mais aussi de nouvelles nuisances jusqu'alors "masquées" par le bruit : les odeurs par exemple.

- l'esthétique des doubles-fenêtres (vues de l'intérieur) qui est contestée par 41 % des résidents et qui semble avoir un lien avec le niveau de gêne "Après" ;

- la non protection des espaces extérieurs liés aux logements (lieu de détente, de loisirs, de rencontre) ; ces espaces étant de ce fait "sous-utilisés", peu entretenus, voire laissés à l'abandon.

IV - IMPACT DES ENROBES DRAINANTS

Peu de recherche ont jusqu'ici évalué l'impact de la mise en place de chaussées peu bruyantes sur la population résidante en zone urbaine. Quelques résultats sont cependant disponibles pour la France. Ils concernent les villes de Paris et Nantes dans lesquelles une enquête psychosociologique "Avant-Après" a été menée en 1989 [12].

La réduction des niveaux sonores exprimée en LAeq atteint 0,5 à 4,5 dB(A) suivant les points de mesures et les moments de la journée (Tableau 3).

Tableau 3. Diminution des niveaux sonores consécutive à la mise en place de chaussée peu bruyante

Période	Paris		Nantes		
	Site 1	Site 2	Site 3	Site 4	Site 5
8h - 20h	2,9	2,8	2,1	3,7	4
20h - 24h	3,9	4,2	1,7	3,1	1,7
0h - 5h	3,7	4,4	0,4	2,9	1,0
5h - 8h	2,4	3,1	1,6	2,9	2,2

Face à ces réductions des niveaux sonores, l'enquête menée auprès de la population montre que :

1/ Une proportion importante (54 %) de la population estime qu'il y a moins de bruit dans la rue que précédemment à cause du nouveau revêtement (88 %).

2/ Près d'une personne sur deux (45 %) estime que le bruit a changé de nature ; la majorité d'entre elles (62 %) estimant que le bruit est maintenant plus grave.

3/ Une variation relativement faible du niveau moyen de gêne (Tableau 4), excepté dans le site 2 situé à Paris, particulièrement bruyant initialement (chaussée en pavés - niveau de jour supérieur à 73 dB(A)). Dans ce site on enregistre d'ailleurs une amélioration très sensible de la qualité de sommeil des résidents parallèlement à une diminution de plus de 4 dB(A) des niveaux sonores en soirée et surtout la nuit.

Tableau 4. Niveau moyen de gêne "Avant-Après" mise en place de la chaussée peu bruyante

Site d'enquête	Niveau moyen de gêne (échelle en 7 points)		
	Avant	Après	Différence
Site 1	3,58	3,38	- 0,20
Site 2	4,37	3,31	- 1,06
Site 3 à 5	4,12	4,18	+0,06

On notera, pour les sites de Nantes (3 à 5), un écart entre ces résultats (niveau moyen de gêne inchangé) et ceux concernant la variation entre la gêne Avant et la gêne Après estimée par la population lors de l'enquête Après : 54 % des personnes interrogées estiment être moins gênées Après qu'Avant.

4/ 19 % de l'ensemble de la population enquêtée estiment mieux dormir (30 % dans le site 2 à Paris), bien que, globalement elles disent être autant réveillées la nuit par le bruit qu'auparavant.

5/ 30 % de l'échantillon considère que la qualité du quartier s'est améliorée.

Cependant la relation bruit/gêne n'est pas très significative. On peut faire l'hypothèse qu'une réduction minimale des niveaux sonores est nécessaire, notamment en soirée et la nuit, pour que l'on puisse observer une diminution significative de la gêne, comme on peut le constater dans le site 2 à Paris. Alors l'exposition au bruit de nuit et en soirée "décideraient" de la satisfaction des riverains.

V - IMPACT DES MESURES DE GESTION DE LA CIRCULATION

Diminuer la gêne et plus généralement les effets du bruit peut également être atteint par la mise en oeuvre de mesures concernant la circulation, telles que :

- la déviation du trafic de transit sur des voies de contournement situées en périphérie de ville (notamment les poids lourds) ;

- la limitation des vitesses dans les zones résidentielles (Tempo 30 en Allemagne, zone 30 en France) ;

- plus généralement la restriction ou la modération du trafic en zone urbaine.

Bien que ces mesures ne soient pas prises directement pour des raisons de bruit, mais pour des objectifs de réduction des encombrements ou d'amélioration de la sécurité routière, elles n'en ont pas moins des effets sur l'environnement urbain sonore. Toutefois, assez peu d'enquête ont tenté jusqu'à présent d'évaluer ces effets sur les résidents [13 - 14].

L'enquête sociale menée par J. Kastka auprès de 1700 résidents [15] est intéressante. Elle montre que pour une très faible réduction moyenne des niveaux sonores (1 dB(A) environ du Leq 6h-22h), on a obtenu une diminution importante de la gêne due au bruit. Cet effet positif sur le niveau de gêne correspondrait à une réduction théorique des niveaux sonores comprise en 6 et 14 dB(A). La seule diminution des niveaux sonores apparaît ainsi insuffisante pour expliquer la diminution de la gêne. Il semble donc que, pour une diminution identique des niveaux sonores, la réduction du volume de circulation ait des effets plus importants sur le niveau de gêne que d'autres types de mesures comme la mise en place d'écrans acoustiques ou l'insonorisation des logements.

Une enquête très récente menée Avant-Après mise en place d'une déviation dans une petite ville de France [16] permet d'avoir une idée assez précise de la diversité des effets obtenus par ce type de mesure.

Dans le centre de la ville, là où le trafic a été réduit, l'environnement sonore a subi des modifications importantes. Dans la rue principale, les niveaux sonores, initialement très élevés (LAeq 8h-20h > 70 dB(A)) ont diminué de 3 à 7 dB(A) (due principalement à une forte réduction du nombre de poids lourds). La gêne moyenne a fortement baissé ainsi que le pourcentage de personnes très et excessivement gênées (Tableau 5).

Tableau 5. **Niveau de gêne due au bruit avant-après déviation**

Niveau de gêne	AVANT	APRES
1 : pas gêné	5.7%	15.7%
2 : peu gêné	10.0%	21.4%
3 : gêné	17.2%	45.7%
4 : très gêné	17.2%	11.4%
5 : excessivement gêné	50.0%	5.7%
Gêne moyenne	4	2.7

Cet effet positif de la déviation sur la gêne est confirmé si on considère la fréquence de perturbation de certaines activités au domicile (Tableau 6).

Tableau 6. Activités souvent perturbées et comportements avant-après déviation

	AVANT	APRES
Sursaut	11,4 %	1,4 %
Conversation	22,8 %	8,5 %
Ecoute TV	42,9 %	21,1 %
Lecture, écriture	17,2 %	2,8 %
Endormissement le soir	20,0 %	2,8 %
Réveil le matin	15,7 %	2,9 %
Chambre non-utilisée	20,0 %	7,0 %
Fermeture fenêtre	71,4 %	43,6 %

A l'inverse, le bruit de voisinage, bien que pas plus cité qu'auparavant en tant que source de bruit perçue, est ressenti comme plus gênant.

Au-delà de ces effets classiques, les résidents sont beaucoup moins nombreux à envisager de quitter leur quartier (47 % avant déviation - 10 % après déviation). Ils considèrent que le cadre de vie de leur quartier s'est sensiblement amélioré et que la rue principale qui traverse la ville est certes moins bruyante, mais aussi plus sûre, plus propre et plus facilement franchissable qu'auparavant.

En ce qui concerne les riverains qui habitent le long de la déviation (voie autoroutière), le changement est inverse, mais d'ampleur plus limité :

- les niveaux sonores, bien qu'encore modestes (LAeq 8h-20h = 50 à 55 dB(A) après ouverture de la déviation) ont augmenté de 4 à 8 dB(A) à cause notamment de la part importante du trafic de poids lourds.

- la note moyenne de gêne est passé de 1,7 à 2,9 (échelle en 5 points) ; le pourcentage de personnes très gênées et excessivement gênées par le bruit routier a été multiplié par 2,3 ; le bruit est considéré comme inacceptable par plus de 70 % des personnes interrogées.

- bien que la fréquence des activités perturbées n'ait pas variée de façon significative (mais les niveaux d'exposition au bruit sont encore assez peu élevés), certains indices indiquent de réelles modifications comportementales qui toutefois n'atteignent pas celles rencontrées dans des zones fortement exposées au bruit (Tableau 7).

Tableau 7. Comportements dûs au bruit le long de la déviation

Souvent et parfois	AVANT	APRES
Ferme les fenêtres	46,7 %	61,6 %
Limite l'utilisation du jardin, du balcon	16,7 %	24,0 %
Chambre non-utilisée	6,7 %	21,6 %
Intention de déménager	6,6 %	21,2 %

VI - PRINCIPAUX ENSEIGNEMENTS

Le premier objectif poursuivi est la limitation ou la réduction de la gêne globale ou comportementale ainsi que des activités perturbées au domicile (sommeil, écoute TV, conversation etc). L'importance

de ces impacts dépend toutefois d'un grand nombre de paramètres, soit liés directement au bruit (diminution des niveaux sonores, modification du spectre), soit liés à des facteurs psychosociologiques.

On observe également l'apparition de multiples effets secondaires ou induits positifs de nature très différente ; par exemple : réutilisation et donc revalorisation des logements et des espaces extérieurs situés à proximité (jardin, espaces collectifs de jeux ou de détente), revitalisation des relations sociales entre les habitants des zones protégées, diminution de la pollution de l'air et des poussières provenant de l'extérieur et économies d'énergie dans le cas d'une meilleure isolation contre le bruit, sentiment d'une plus grande sécurité lorsqu'un écran acoustique est placé entre les bâtiments et la voie routière ou lorsque l'on procède à une déviation du trafic de transit.

Mais ce bilan peut être plus nuancé lorsque des effets induits négatifs apparaissent : émergence de sources de bruit jusqu'alors masquées (en particulier le bruit des voisins tant à l'intérieur qu'à l'extérieur des logements), non protection des espaces extérieurs dans le cas de l'isolation de façade, intrusion visuelle et esthétique parfois contestable des écrans phoniques notamment en zone rurale.

Cette multiplicité des impacts conduit à s'interroger sur la méthode d'évaluation de l'efficacité des mesures de protection contre le bruit. En parallèle à l'approche uni critère en termes de "gains acoustiques prévisibles - variation du niveau de gêne" qui apparaît très réductrice, on privilégiera une approche multicritère de l'évaluation des impacts. Cette méthode, insuffisamment développée actuellement, peut se révéler particulièrement adaptée aux situations qui, en regard d'une faible diminution des niveaux sonores, conduit tout de même à une diminution assez sensible de la gêne.

Aussi des travaux de recherche mériteraient d'être entrepris dans cette direction afin que les décideurs puissent disposer d'une information aussi pertinente et complète que possible pour éclairer leurs choix.

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CHAIRMAN'S SUMMARY
INTERNATIONAL NOISE TEAM 6:
COMMUNITY RESPONSE TO NOISE

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During the past five years, research on community response made some progress in its eternal struggle to comprehend at least something of what is going on in people's minds in relation to noise pollution. And perhaps more important: we made some progress in advising our governments in their attempts at noise abatement.

An important development which has become apparent in the past five years has been the shift of emphasis from carrying out many large, expensive and time-consuming field surveys, to compiling and more thoroughly analyzing already existing ones, a development, previously advocated by our honourable colleague Ragnar Rylander in 1978, during a workshop on railway noise, also in France. The use of secondary analyses of previous surveys has been illust· ·d at the present conference by papers on ambient noise and reactions to different noise sources.

Other papers reviewed previous work and presented new work on the following important topics: the effectiveness of noise reduction measures, the reaction to changes in noise exposure, penalties associated with impulse noise, the relative importance of alternative noise descriptors, the impact of non-acoustical parameters, and reactions to noise in non-residential settings.

Several of the attempts to combine results from previous studies proved to be very useful. However, participants also identified difficulties in utilizing data from divergent types of surveys. Partly as a result of such observations, the team decided that a major focus for their future objectives would be to facilitate the comparisons of the results from different studies.

The Team 6 objectives for the 1993-1998 period are shown in table 1. Each of six goals contribute to our central objective of enhancing the possibilities of benefiting from each others experiences.

First we plan to propose minimal community noise survey reporting guidelines. We would expect to suggest that all publications include such features as an exact reproduction of relevant interview questions and specification of the details of the noise measurement or noise estimation procedures.

Second, we wish to make it easier for researchers to conduct secondary analyses of large numbers of data sets. To that end we hope to be involved in the establishment of an easily accessible dose/response archive. Such an archive might include entire data sets or, perhaps, only information about the basic dose/response relationship.

Table 1 Objective and goals set for 1993-1998

CENTRAL OBJECTIVE
Enhancing the possibilities to benefit from other researchers' data.

GOALS

1. Developing social survey reporting guidelines.
2. Promoting the establishment of a dose-response data archive.
3. Advocating the use of at least one previously used, shared annoyance question - supported with the availability of previous data.
4. Advocating the use of at least one shared physical noise index or the publication of transfer functions for estimating it from the published data.
5. Pomoting educational courses.
6. Establishing guidelines for the design and execution of social surveys.

Third and fourth, we believe that the comparability of study results would be greatly enhanced if researchers included at least one common annoyance question and noise measure in their surveys. Let me emphasize that we are NOT stating that all surveys must be restricted to a single type measurement. Each survey will need a variety of types of annoyance and noise measures. We are simply suggesting at least one noise and annoyance measure should be shared between surveys. We hope to support and stimulate the use of such shared measures by providing a compilation of the results from previous surveys which have used these measures.

Fifth, the need to enhance the quality of community surveys has been recognized in our desire to promote the establishment of educational courses which would focus on dose/response survey methods.

Sixth and last, we wish to identify other desirable characteristics for community noise surveys. We hope that publishing a list of such characteristics might enhance the quality of the survey data and provide assistance for researchers planning new surveys.

In striving towards achieving these goals, we hope to give a new impetus to high quality community response research.

La réponse sociale du bruit
Résumé de la session 6

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Pendant les 5 dernières années, la recherche sur la réponse sociale a fait quelques progrès dans son éternelle lutte pour comprendre ce qui se passe dans la tête des gens confrontés à la pollution sonore. Le plus important étant que nous progressons en informant nos gouvernements sur les actions de réduction du bruit qu'ils peuvent mener.

Une évolution importante est apparue ces cinq dernières années. La mise en place d'études portant sur des domaines trop vastes et consommateurs de temps a été remplacée par la compilation et l'analyse d'études qui existent déjà.

Cette évolution avait été défendu auparavant par notre honorable collègue Ragnar Rylander en 1978 lors d'une séance de travail sur le bruit des trains qui se passait également en France. L'utilisation de ces analyses secondaires a été illustrée pendant cette conférence par des papiers sur le bruit ambient et les réactions aux différentes sources de bruit.

D'autres papiers retracent des travaux antérieurs et présentent un nouveau travail sur les thèmes suivants : l'efficacité des mesures de réduction du bruit, la réaction aux changements d'exposition au bruit, les handicaps associés avec les bruits impulsionnels, l'importance relative des descripteurs du bruit alternatif, l'impact des paramètres non acoustiques et les réactions aux bruits des établissements non résidentiels.

Plusieurs des essais de combinaison des résultats des études antérieures ont fait la preuve de leur utilité. Toutefois, les participants ont rencontré également des difficultés en utilisant des données de types divergents d'études.

En partie grâce au résultat de ces observations, l'équipe a décidé que le point majeur de ses futurs objectifs sera de faciliter les comparaisons des résultats des différentes études.

Les objectifs de l'équipe 6 pour la période 1993-1998 sont montrés dans le tableau 1.Chacun des 6 buts contribue à notre objectif central qui est d'augmenter les possibilités de chacun de bénéficier des expériences des autres
.

Premièrement, nous proposons au minimum des directives d'études du bruit social. Nous suggérons que toutes les publications incluront des caractéristiques communes telles qu'une reproduction exacte des questions des interviews et que la spécification des détails des mesures du bruit ou des procédés d'estimation de celui-ci.

Deuxièmement, nous souhaitons faciliter aux chercheurs la conduite des analyses secondaires sur un nombre important de renseignements. A la fin nous espérons arriver à l'établissement d'une banque de données question/réponse accessible facilement. Une telle banque doit inclure des jeux entiers de renseignements ou peut-être seulement des informations sur les relations courantes question/réponse.

Tableau 1 Objectifs et buts pour 1993-1998

Objectif central Augmenter les possibilités de bénéficier des renseignements des autres chercheurs
BUTS
1- Développer des directives pour les études sociologiques 2-Promouvoir l'établissement d'une base de données sur les questions/réponses 3-Défendre l'utilisation finale d'un questionnaire de gène préalablement utilisé, partagé, supporté avec la validité des renseignements antérieurs 4-Défendre l'utilisation finale d'un index de bruit physique partagé ou la publication de fonctions de transfert pour l'estimer depuis la banque publiée. 5-Promouvoir des cours éducatifs 6-Etablir des directives pour la désignation et l'exécution des études sociologiques.

Troisièmement et quatrièmement, nous croyons que la comparaison des résultats d'études pourra grandement augmenter si les chercheurs incluent finalement un questionnaire de gène et de mesure de bruit commun dans leur étude.

Laissez-moi attirer votre attention sur le fait que nous n'avons pas proposé que toutes les études soient réduites à un seul type de mesure. Nous avons simplement suggéré qu'une mesure de bruit et de gène doit être partagée entre les études.

Nous espérons supporter et stimuler l'utilisation de mesures partagées en proposant une compilation des résultats d'études antérieures qui ont utilisées ces mesures.
Cinquièmement, le besoin d'augmenter la qualité des études sociales a été reconnu dans notre désir de promouvoir l'établissement de cours qui se recentreraient sur les méthodes d'étude dose/réponse.

Sixièmement et enfin, nous souhaitons identifier d'autres caractéristiques désirables pour les études du bruit sociologique. Nous espérons que la publication des listes de telles caractéristiques augmentera la qualité des renseignements et l'assistance préalable pour permettre aux chercheurs de planifier les nouvelles études. En s'efforcant d'atteindre ces buts, nous espérons donner un nouvel élan à la recherche sur la qualité de la réponse sociale.

EVALUATION OF ANNOYANCE AGAINST TRANSPORTATION NOISES WITH RESPECT TO READING AND LISTENING ACTIVITIES

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ABSTRACT

This paper describes a simulation laboratory experiment to determine the effects of noise level and source type on annoyance while performing reading and listening activities in daily life. 64 subjects were tested in three sessions consisting of two consecutive parts under the continuous noise conditions. Road ,railway and aircraft noises were simulated by the samples recorded in the field with varying noise levels between 30 to 55 dBA Leq(30 min.) and with the pass-by numbers changing 8,12,16/30 min. Indoor noise samples were prepared by taking into account the facade and the room characteristics. Results indicated that source type was not a significant factor in activity disturbance, on contrary to some previous studies and the railway noise was almost equally annoying as the road traffic noise. The increasing effect of noise levels was emphasized especially for the listening activity at 45 dBA where the noise & response curvatures for both activities coincide.

INTRODUCTION

Experiments dealing with the effects of noise on activity disturbance concern the three aspects:

1. Interference with a mental task (non-auditory task related to short term memory performance; like concentration on reading,solving a problem etc.)
2. Interference with speech intelligibility (auditory task influenced by masking)
3. Sleep disturbance

The difficulty and the compexity of the task depending on its verbal or visual characteristics, the physical nature and the meaning of the noise,exposure time and selected criterion for the task performance (accuracy or speed) are important factors in evaluation of the task performance. Similarly, the listening activity is affected by signal / noise ratio, frequency content, fluctuation and intermittency of the noise and masking time.

Regarding the subjective response to noise, the activity disturbance is evaluated from the standpoint of acceptability and annoyance which is defined as unwantedness by both auditory and non-auditory factors, like individual and environmental aspects. In the field studies, the respondents are asked about their annoyance degrees while doing different activities at home with their windows closed and open; such as conversation, reading, doing mental work, listening TV-radio or sleeping. However,despite the outdoor noise levels precisely measured to obtain the noise & annoyance relationships, it is difficult to determine the exact indoor noise conditions, while these activities are performed in different parts of the building.

In annoyance studies carried out in anechoic room or in simulated environment laboratory, subjects performed a relaxation activity involving somewhat concentration, such as reading magazines, playing cards, filling some forms etc. under the controlled noise conditions (1,2,3). Rice in his earlier experiment, delibately chose a speech environment and aimed to investigate "the interference with the ability to relax and to enjoy listening to the spoken world" (4). He found L10=45 dBA as an acceptable indoor noise level for traffic noise ,while Williams and Langdon declared that Lmax= 75 dBA for aircraft noise remained in the "barely acceptable region" for the listening activity (5). Hall and Taylor indicated that the speech interference can be noticeable at Lmax=50 dBA at the listener's ears (6). On the other hand, Rice in his NASA study, declared that "a relaxation activity involving concentration is not unduly interfere with the subjective responses".(1)

This paper aims to determine and compare the disturbances while performing the common visual and aural activities in daily life under varying transportation noise conditions.The parameters are the type of noise source (road,railway and aircraft) and the noise levels varying between 35-55 dBA Leq(30min.).The vehicle pass-bys are 8,12 and 16 / 30 min. for the intermittent noises like railway and aircraft traffic and the road traffic noise is continuous during the test.

EXECUTION OF THE EXPERIMENT

This study was carried out in Kobe University, Japan ,by means of a grant provided by Japan Society for Promotion of Science (7). The simulated environment method which was used in this study has been widely described in the previous literature and it was evidenced that a 30 min. was sufficient test duration in annoyance simulations in case the simulation of environment and noise conditions are achieved satisfactorily.

The total number of the subjects participated in the experiment after the audial tests was 64 divided into 16 groups, each group taking the three sessions.The 3x3x3 balanced Latin Square Design was applied in the presentation of noise samples to the groups, in order to eliminate the carry over and adaptation effect. A special questionnaire was prepared parallel to those of the field surveys and included the questions: 1.about the individual characteristics of the subjects, 2.about the annoyance degrees during reading and listening, 3.about overall annoyance at the end of the session.

Basing on the 1-7 point annoyance scale, the individual and group average scores (SSV) ,as well as the percentages of highly annoyed subjects(HA %), were obtained and used as annoyance descriptors in the evaluation of the data.

Simulation of Indoor Environment

A listening room of 25 sqm with a special construction apart from the main laboratory building and connected to a control room was rearranged for this experiment. It was furnished as typical living room and 8 flat-type loudspeakers were placed behind a screen which was used as a false window (Figure 1). Noise sources were visualised by a video-projector located in the control room and by the video films shot in the field where the noise samples have been recorded. In the first half of the 30 min. test duration; the subjects were required to read an article from a magazine carefully, so as to write a resume afterwards, and in the second half; they were given some listening tapes including a play recorded from the radio. Each group took 3 different tapes during the three sessions. Max.speech level was kept at 65 dBA in the receiver position and was controlled outside.

Simulation of noise

Noise samples for aircraft, railway and highway noises were recorded at real sites without having an obstruction around. The two microphone positions giving 70 and 50 dBA(Leq 30 min.) were selected to be able to keep the natural fluctuations of the noise due to distance effect. Master tapes were then processed in the laboratory to control some parameters, such as; number of pass-bys; Leq and peak levels of the noise and background noise that were kept 12-25 dBA lower than the peak levels. A transfer function including the transmission loss of the facade which was supposed to be consisting of 40 % windows with normal glazing, as well as the room absorptivity and the loudspeaker characteristics, was calculated and applied to the signals electronically via a computer while giving into the room. The indoor noise levels were monitored by a ceiling microphone, a graphic-level recorder and a Leq meter.

EVALUATION OF THE RESULTS

Variation of annoyance responses reported by the subjects during reading and listening activities were statistically analyzed and summarized below. The overall annoyance has been presented elsewhere (10).

The t - tests applied to the raw data for comparison of reading and listening annoyances, indicated a significant difference between the distributions of the two groups (at 0.0001 level of significance).Further analyses were made to investigate the variation of annoyance with noise level for each activity and to determine the dependency of annoyance on the source type. SPSS PC+(IBM) and Cricket (Mac Intosh) softwares were used in the calculations.

Fig.2a gives the line charts prepared by taking the average group scores for the combined data as independent of source type and pass-by number. The increase of annoyance as expected, was confirmed for both activities with more abrupt increase formed by the listening annoyance at Leq=45 dBA, where the both lines have coincided at this threshold. This result is about the same in the graphs involving the HA% and, the difference between the two activity disturbances at 55 dBA is 18%, implying a higher annoyance while listening (Fig.2b). This difference corresponds to 2 SSV in terms of group average scores at the same level.

Correlation tests indicated a higher relationship between listening annoyance and noise levels for the average scores, as can be seen in Table 1. Regression analyses gave the below relationships for both annoyance descriptors and activities

SSV(reading) =0.126 Leq -2.53 (St.error=0.623) HA%(reading) =0.941 Leq -30.53 (St.error=11.55)
SSV(listening)=0.191 Leq -4.87 (St.error=0.79) HA%(listening)=0.3.03 Leq -110.10 (St.error=23.8)
SSV: group average scores , HA%: Percentage of highly annoyed subjects (6. & 7.scores)

The second degree regressions calculated for both activities and given in the Fig. 2 and 3 reveal two inverse functions; the reading annoyance tends to have a more steady curvature, while the listening annoyance presents an increase upwards at higher noise levels.

<u>Analysis for individual sources</u>

When the annoyance & noise level relationships for each source type were seperately investigated ,the results have not come out as expected on the basis of previous studies. The effect of source type has not been evidenced as a significant factor in both activities after the variance analyses giving the significance levels of 0.099 and 0.111 respectively for reading and listening annoyances. The graphs in Fig.4 and 5 give the comparison of three sources for Leq. However a rough estimation can be made about the most annoying sources during reading and listening activities at home : railway is more disturbing at low and moderate levels and both railway and road traffic are equally annoying at high levels. The effect of aircraft remains lower that of the other sources. The dominancy of the railway noise on contrary to the previous experiments , might probably be due to the subjects' previous experience to noise ,since the transportation in Japan is vitally dependent upon the surface railway systems passing through closely in the housing layouts and the typical Japanese houses have been constructed with relatively weaker insulations. The lower annoyance from aircraft noise can be explained by the side- flights used in this experiment, instead of over-head flights in the other studies in which the additional effect like "fear of crashing " was evidenced to have increased the annoyance.

Consequently, there are some disagreements between the patterns of noise annoyances obtained in this experiment and in the previous investigations carried out 10 or 15 years ago. This time difference might have caused a remarkable decrease in the tolerances of the people against the transportation noise sources that are widely spreading in residential communities.

The results were compared with the findings of Langdon and Williams revealing a 10 dB increase with the doubling of dissatisfaction during listening under aircraft noise exposure. For the same amount of pass-by number (8-16 flights/half hour) the similar amount of increase is confirmed in this study in the range of Lmax = 55-75 dBA .

CONCLUSION

Reading and listening activities that are performed under the transportation noise exposures of different types. are mostly influenced by the noise levels, rather than the source type and pass-by number in the given range (8,12,16/30 min.). Annoyance during listening is highly increasing after Leq=45 dBA and in this study it corresponds to about Lmax=55 dBA. Since Hall& Taylor had suggested that Lmax=58 dBA represented 50% of people reporting the speech interference in the field studies (6),it can be suggested that the sudden increase of annoyance starts just before the speech interference and ,the subjective responses to noise are directly related to the objective performance evaluations. On the other hand ,the results of the previous experiments pointing out the road traffic noise or aircraft noise to be more annoying noise in urban areas, have not been evidenced in this experiment in which the railway noise was found to be equally annoying in the Japanese communities.

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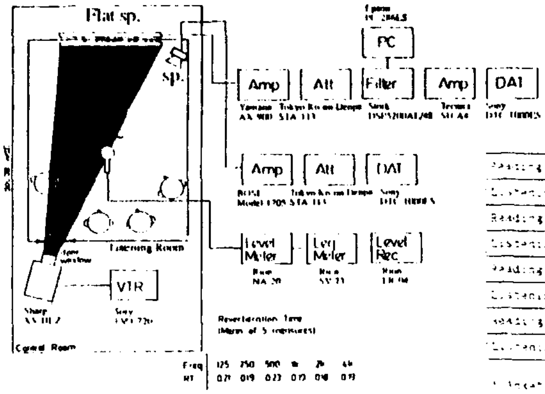


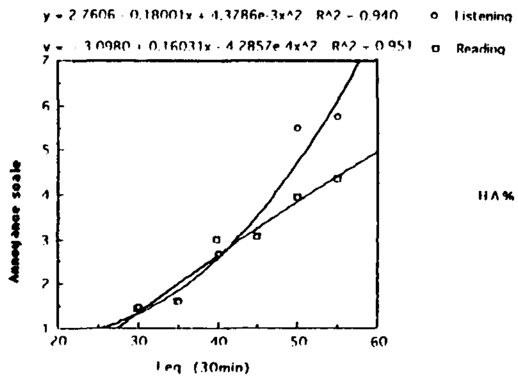
Figure 1 Simulated environment laboratory and instrumentation used in the experiment

	Individual Scores(1) n=132	Average Scores(2) n=30	HA % (3) n=30
Reading & Noise Level (Leq)	0.5634 **	0.8715 **	0.5817 **
Listening & Noise Level (Leq)	0.7536 **	0.9033 **	0.7436 **
Reading & Source Type	0.0467	0.1295	0.1217
Listening & Source Type	0.2903	0.1260	0.3226
Reading & N	-0.0587	[illegible]	[illegible]
Listening & N	[illegible]	[illegible]	0.0403
Reading & Noise Level (Lmax)	----	[illegible]**	[illegible]*
Listening & Noise Level (Lmax)	----	[illegible]**	[illegible]**

(1) Anket1 results *= .01 **= .00
(2) Anket2 results
(3) Anket3 results

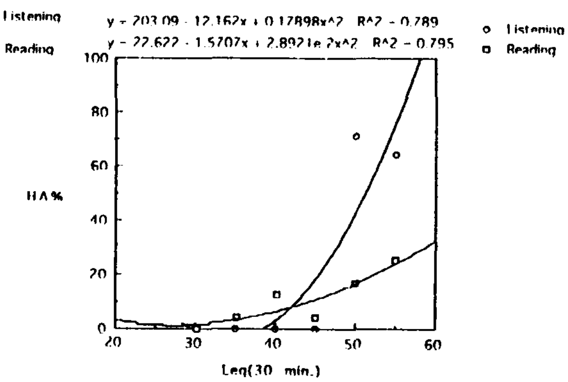
Table 1 Correlations between activity type and source & noise factors

Comparison of reading and listening annoyances



2a. For group average scores

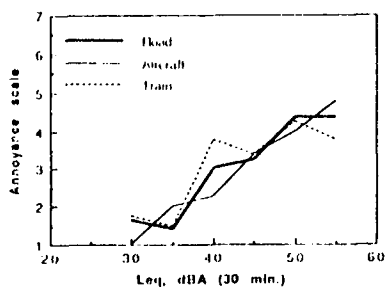
HA% & noise level relationships



2b. For percentage of highly annoyed subjects

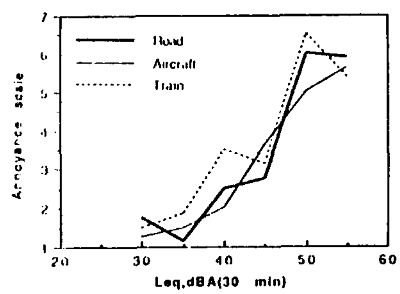
Figure 2 Variation of activity disturbance with noise levels

Comparison of three sources(QS.12b)



3a. For reading

Comparison of three sources (Qs.13b)



3b.For listening

Figure 3 Activity disturbance for individual sources

SUBJECTIVE EVALUATION OF VARIOUS NOISES IN FREE AND QUASI-DIFFUSE SOUND FIELD

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ABSTRACT

In purpose to investigate the relations between the subjective noise impression and the objective measures used today, psychoacoustic experiments were performed in free and quasi-diffuse sound fields by using a method of magnitude estimation. The subjects' answers were transformed to subjective loudness level values ("subjective phon") to express the answers in terms of a constant reference noise. Relationship between A-, B-, C-, D- and Lin- weighted equivalent and maximum sound pressure levels (SPLs), calculated phon-values and subjects' answers were statistically analyzed. The results show quite a large spread and great individual differences, but the regression line for the "subjective phon" and for calculated objective phon values had a slope giving statistically best expression of the subjective impression. Various types of noises were also grouped and correlated with the objective measures showing some differences.

INTRODUCTION

Several attempts have been made to find a method which correlates best with the subjective impression of various noises, in purpose to describe noise annoyance, noisiness and limits for hearing damage. As a results of such efforts, the A-, B-, C-, D- and Lin- weightings have been internationally standardized. None of these weightings has alone been found satisfactory to describe our experience of various noises (both frequency and level). Later research has discussed other means to evaluate noise, i.e. measures based on other psychological attributes like annoyance and noisiness. In this study, the basic has been the well-known psychological, or rather physiological, attribute loudness. Loudness has its basis in the structure of our hearing sense, i.e. in the amount of nerve cell exitation, position on the basilar membrane and type of nerve firing (Stevens & Davis, 1938, 1983).

MATERIALS AND METHOD

The experiments were performed in an anechoic room with a specific loudspeaker arrangement. Four loudspeakers were placed in corners of a tetrahedron and the test subject was placed in the centre point of the tetrahedron. Noises recorded in industrial and other work places, outdoors from transportation, shooting, synthetic reference noise spectra etc. (43 different noises in total) were presented to test subjects in a specific manner as descibed below. Two types of sound fields were shifted by alternating use of one frontal loudspeaker (Altec Lansing 604-8K Duplex) or all four loudspeakers, i.e. consequently free and quasi-diffuse sound field. The whole test was automatically driven by a data machine (MacIntosh SE/30) with a sound editing program (Sound Tools).

The noises were presented in six test sequencies, each lasting about 27 min. Two such sequencies with a pause of about 15 min in between, were presented at three separate days. The test

sequencies consisted of pairs of reference and test noises arranged as given in figure 1. The duration was 1 s (industrial and other) or 10 s (transportation) with 50 ms rise and fall times. Three different levels of noises (adjusted to 65, 80 and 95 dBLin at the centre point) were arranged after each other in random order. The equivalent and maximum SPLs with time weighting "Fast" were measured for all noises (Norsonic 830 with Brüel & Kjær 1/2" microphone). Sone- and phon-values were calculated (Norsonic 830, calc.program acc. to ISO 532).

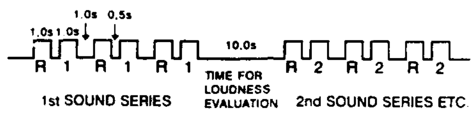

Figure 1. Presentation of test sequencies for the test subjects (R = reference sound of 1/3 - octave band pink noise; 1,2, 3, 4, ...= noise to be evaluated)

Totally 61 test subjects (29 males and 32 females) at three different age groups were used in the tests (18 - 30, 40 - 50 and 60-70 years). The pure-tone audiometric hearing thresholds of the subjects were taken by using GSI 16 Audiometer with TDH 59 ear-muffs. Only subjects with normal hearing thresholds for their age according to ISO 7029 were used.

The subjects were instructed to give numerical values for their loudness impression of the noises by halfing, doubling, tripling etc. on an infinite scale compared to the reference sound of filtered 1/3 octave band pink noise with centre frequency 1 kHz. The reference sound was presented with a constant sound pressure level of 80 dBLIN and was given the numerical value 100.

RESULTS

The subjects' answers were transformed to subjective loudness level values (hereafter called "subjective phon") by using the formula for calculating relationship between sone and phon values according to ISO 532, to express the answers in terms of the equally loud reference noise. The transformed values were then used in simple and multiple linear regression analysis (SYSTAT 5.1). Figure 2 shows a plot of the transformed values of subjects answers.

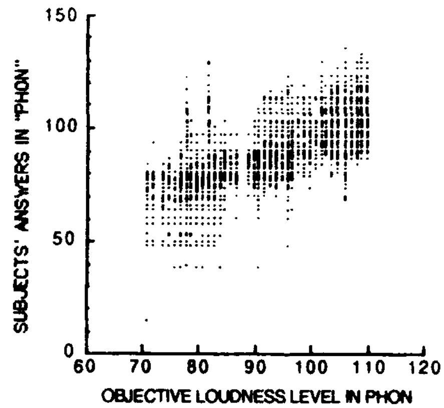

Figure 2. Transformed values of subjects' answers for all types of noises plotted against the related objective calculated phon values

The regression line for "subjective phon" and objective phon values for all used noises had the best slope of all the different weighted maximum og equivalent SPLs (see table 1).

Table 1 Regression data for different weightings of all types of noises and subjects' answers

VARIABLE	CONST	SLOPE	S.E.	N	P	$S.E._{res}$	R^2
PHON	-0,35	0,93	0,006	15725	0,000	7,8	0,641
$L_{A,eq}$	22,6	0,83	0,005	16436	0,000	7,8	0,643
$L_{A,max}$	19,1	0,84	0,005	16436	0,000	7,7	0,649
$L_{B,eq}$	20,4	0,84	0,005	16436	0,000	7,8	0,639
$L_{B,max}$	17,6	0,84	0,005	16436	0,000	7,9	0,637
$L_{C,eq}$	20,4	0,84	0,005	16436	0,000	7,9	0,630
$L_{C,max}$	17,8	0,83	0,005	16436	0,000	8,0	0,622
$L_{D,eq}$	19,4	0,80	0,005	16436	0,000	7,9	0,637
$L_{D,max}$	15,3	0,82	0,005	16436	0,000	7,8	0,646
$L_{Lin,eq}$	20,1	0,84	0,005	16436	0,000	7,9	0,631
$L_{Lin,max}$	17,4	0,84	0,005	16436	0,000	8,0	0,625

The other variables incorporated in the tests, namely age, sex, type of sound field, difference between maximum and equivalent values, duration of the noises and startle reactions, were analyzed by using multiple regression analysis. The noise position in the listening series was also tested to look for possible effects of the preceeding noise on the evaluation of noise under test.

Comparison of free and quasi-diffuse field separately showed almost overlapping regression lines. The slope for quasi-diffuse field was a little lower than that of the free field, but the difference seems not to be significant. The increase in noise duration affected the results upwards. The youngest age group evaluated the noises at lower intensities about 8 "phon" higher than the two older groups. The regression lines for men and women were almost the same, i.e. for women approximately two "phon" higher than for men. The difference in maximum and equivalent SPLs seems to have an effect to the loudness evaluation, i.e. increasing loudness with increasing difference. Startle reactions had same type of effect.

The different types of noises were also grouped and correlated with the objective measures. All groups, except the heavy road vehicle and train noises, had the best regression with the objective calculated phon values. Comparing of synthetized reference, impulsive and transportation noises results to about 10 "phon" louder evaluation of transportation noises than of the synthetized reference noises at the low levels. The heavy road vehicles were almost 20 "phon" more loud than the light-weight vehicles at the lower sound intensities. Trains were evaluated more loud at lower sound intensities than the airplaines and road vehicles. Road vehicles were again evaluated more loud than airplanes. Regression line of "subjective phon" for train noise and objective phon had the lowest slope value of all noises. Regression lines for shooting and airplanes were overlapping.

DISCUSSION

The regression line for the "subjective phon" and for calculated objective phon values had a slope giving statistically best "weighting" to express the subjective impression. This is not difficult to understand due to the origin of the other weightings from different levels of loudness or noisiness curves (Croom, 1977), and the original purpose of using these to measure special types of noise. However, the results show quite a large spread and great individual differences. The effects of the different other variables were minor compared with the objective measures, but they explain some of the variation in the results.

The younger people evaluate the low level sounds higher which has a possible explanation in the change in the hearing threshold with increasing age and recruitment phenomen for the older people. The sex might also have a slight effect to the higher loudness evaluation of noise. The

two field situations seem to be evaluated as loud which corresponds with the recently presented hearing level contours for these two field situations (revised ISO 226, 1993). This would not be the case for low frecuency sounds according to Nielsen & Poulsen in 1993. Noises following a high intensity noise were evaluated less loud than otherwise. This effect was marked especially after some heavy road vehicles. Some earlier reports support this finding (Canévet & Scharf, 1990) while others have found different results (Cross,1973).

The difference in loudness evaluation of light-weight and heavy road vehicles was marked. The heavy road vehicles have also been evaluated to be more annoying than other noises in similar annoyance studies (Öhrström et al., 1980). The evaluation of them might be affected by other psychological attributes than loudness. Evaluation of noise from passing trains had the poorest regression with phon values. This may have some explanation in the changing impulsive noise character of these railway noises. The comparison of loudness evaluation of trains and road vehicles at low levels differ from earlier annoyance studies (Knall et al.,1983)

CONCLUSIONS

The results are not unambigous for all types of noises (and individuals) and the analysis of results are not finished, but some preliminary conlusions can be drawn. There is no doubt that for most of the used noise types (with possible exception of trains and heavy road vehicles), the objective calculated loudness levels describe best the subjective loudness impression of them. It seems therefore, that the general basic for noise measurement technicques should have its origin in loudness curves of different levels, i.e. both frequency and sound pressure level dependent "weighting" as in our ear. In the way the modern sound measurement and analyzing technique has advanced in recent years, production of commercial instrumentation based on our loudness impression should not be a problem. It could also be an advantage to make use of the relationship between loudness, annoyance and noisiness (Berglund et al. 1976, 1981; Scharf, 1974) in solving noise problems.

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EFFECTS OF AIRCRAFT NOISE ON THE PREDATOR-PREY ECOLOGY OF THE KIT FOX (*VULPES MACROTIS*) AND ITS SMALL MAMMAL PREY.

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ABSTRACT

We present the initial results of a three year study of the effects of heavy low-altitude aircraft traffic on the predator-prey ecology of two species, the kit fox (*Vulpes macrotis*) and the kangaroo rat (*Dipodomys* spp.). The study is being conducted on the Barry M. Goldwater Range (BMGR) in Arizona, USA, where these species are exposed to low-altitude overflights of F-15, F-16 and A-10 aircraft. Rates of exposure on the training racetracks of this range can exceed 160 overflights/day and sound levels often exceed 100 dB(A). Potential effects on the animals in the area include hearing damage, sleep interference, masking of predator and prey sounds, and, ultimately, effects on populations.

Small mammal density, age/sex composition, species diversity, recruitment, and survivorship are being measured on 6 1.4 ha study plots, 3 in an area heavily exposed to aircraft and 3 in a matched control area. Fox abundance and home range usage are also being compared.

During the 1992 and 1993 field seasons, populations of small mammals and foxes were high in both exposed and unexposed areas. There were no significant differences in small mammal density between the exposed and unexposed sites ($p > 0.05$). Merriam's kangaroo rats (*D. merriami*) were less common on the exposed study plots in 1992, but there were significant differences in vegetation diversity between control and exposed plots as well. Study plots in 1993 were better matched in vegetation diversity, and preliminary evidence suggests that the difference in density of Merriam's kangaroo rats was an artifact of method. Foxes were more common on the exposed site based on several biased measures in 1992, but were found in similar densities with greater tracking effort in 1993. Seven individuals radio-tracked in the exposed area and 9 tracked in the control area had home range sizes averaging 4.44 (se=0.52) km^2 and 3.89 (se=0.46) km^2 respectively; these home range sizes did not differ significantly (T-test, $P >> 0.05$). Several successful pairs had home ranges completely within the area most heavily used by aircraft.

INTRODUCTION

Many low-altitude military aircraft training routes in the United States are located in desert areas. Ambient sound levels in these areas are very quiet, with A-weighted hourly averages ranging between 20 and 40 dB. Many desert species are nocturnal and depend on acute hearing for survival. In particular, kangaroo rats (*Dipodomys* spp.) are known to have relatively good low-frequency hearing and to depend on their hearing to avoid predators on dark nights (Webster and Webster 1971). They hear well at low frequencies due to a specialized auditory bulla, and their hearing is suspected of being especially vulnerable to noise (Brattstrom and Bondello 1983). One of their major predators, the kit fox (*Vulpes macrotis*), is known to have extremely sensitive hearing that it uses to locate prey sounds (Bowles and Francine unpub data). Despite growing concerns within U.S. management agencies about the effects of noise on animals (Manci *et al.* 1988), the effects of aircraft noise on ecological interactions, such as the predator-prey ecology of these specialized species, have not been studied.

We present the initial results of a three year study of the effects of heavy low-altitude aircraft traffic on the predator-prey ecology the kit fox and the kangaroo rat. The potential effects that are being examined include hearing damage, masking of predator and prey sounds, and effects on populations resulting from disturbance-induced physiological or behavioral changes. We report here on the results of the population studies.

METHODS

The study is being conducted on the Barry M. Goldwater Range (BMGR) in Arizona, USA, where F-15, F-16 and A-10 aircraft conduct training overflights on prescribed racetracks at altitudes as low as 200 ft (65.6 m). Animals are exposed when flights of 1-4 aircraft, called sorties, travel around these racetracks for periods of approximately 40 minutes. These exposures occur both during the daytime, when animals were in burrows or dens, and at night when they forage. Attenuation by burrows and dens is not great, 3-10 dB (Francine unpub.)

The exposed study area lies under the flight pathway (racetracks) of one training range of the BMGR, approximately 20 miles south of the town of Gila Bend, Arizona. The BMGR is transected by a series of ranges of the Sauceda Mountains interspersed by alluvial flats and bajadas. These flats are covered by Sonoran Desert scrublands and cut by washes that support bushy desert trees, mainly paloverde and mesquites (*Cercidium microphyllum*, *Prosopis* spp.). The open flats are the habitat type favored by both kit foxes and kangaroo rats, which were found in abundance during initial surveys in 1991. The training range is bisected by a branch of the Saucedas, and only the southern arm of the racetrack is used; the area under the northern arm is thus available as a fairly well-matched control area (Figure 1).

The range is used for air-to-ground sorties, in which the pilot follows one of several prescribed routes. In the study area, the flight pattern includes extremely low-altitude flight (65 m) and "pop-up" exercises, in which the surface is exposed to directed noise from the aircraft's engines. The principal types of aircraft flown are F-15 and F-16 fighters and A-10 "Warthog" attack aircraft. Most flights occur from 0800 to 1700 hrs, with a slight lull at midday, and from 1900-2100 hrs in the evening.

Characterization of Noise Exposure:

The noise levels produced by the aircraft were measured using community noise monitors (CNM's;Larson Davis 820 and CEL 493/438) and Animal Noise Monitors (ANM's) developed by the U.S. Air Force. The community noise monitors measured A-weighted Lmax, ASEL, and hourly average noise levels (Leq). ANM's measured A- and C-weighted peak, Lmax, and SEL, as well as duration and onset rate of each event. Trigger thresholds of these devices varied somewhat, from Lmax of 70 dB (Larson-Davis 820) to 75 dB (CEL 493/438) to 80 dB (ANM's). Thresholds varied were varied to correct for sensitivity to wind noise and differing threshold algorithms. The devices were deployed at 1.2 m height on a 1 km grid throughout the exposed area to obtain a map of the exposure under the race tracks and in a few selected sites in the control area. Monitors were left running for 6-21 days before being moved to the next sampling site. Measurements were made throughout the field season, but no important seasonal differences in exposure were detected. Spurious noise due to wind was reduced in the CNM's using a 21 cm diameter open-pore foam wind screen.

Studies of Small Mammal Demography:

Small mammals were sampled using an 8x8 grid of Sherman small mammal traps on six 1.4 ha plots, 3 in the exposed area an 3 in the control. The grids in the exposed area were, by

happenstance, located within the home range of a fox or foxes that learned to raid the traps. Therefore,several months of data from 1992 were biased by method-induced losses. Vegetation surveys conducted in 1992 also revealed that vegetation diversity was somewhat lower in the exposed grids than in the control area. Therefore, two of the grids were relocated in the winter of 1993 into an area defended by different foxes with better-matched vegetation diversity. By the time of this change, a good noise map of the study area was available; the two new plots were located under the most intensely traveled portions of the exposed area.

Small mammals were trapped on two nights monthly. Traps were set at night and checked early the following morning to avoid losses due to overheating. Each small mammal was marked, weighed, measured, and examined for sex and reproductive condition, tooth condition, and general health. Small mammals were then returned to the area where they were captured. Densities were calculated using the number of each species captured per ha per sampling period. The proportion of recaptures was used as a second estimate of population size, and to determine recruitment and loss rates.

Studies of Fox Demography, Home Range Usage, and Prey Preferences

Measurements of carnivore density are notoriously biased (Hallett *et al.* 1991). Therefore, several different measures were used to determine the number of kit foxes in the study area. These included monthly trapping surveys for mark-recapture analysis, tracking of radio-collared individuals to determine home range sizes and overlap, and surveys with baited camera stations to develop and index of abundance for small predators. The tracking data were also used to determine home-range usage. Samples of scats collected at denning sites, in traps, and at camera stations were used to determine prey preferences of the foxes.

Foxes were trapped using large raccoon-sized live traps, marked with plastic eartags (NASCO rototags), weighed, measured, and examined for sex, reproductive condition, age, and general health. Traps were set at 1 km intervals along all the roads in both study areas. Effort and area covered were balanced between the two areas. It became apparent that trappability was not uniform among individuals and months, however. Therefore, in 1993, trapping effort was concentrated in December and January, the period when foxes were most likely to enter traps. A total of 12 adult foxes in each area were equipped with radio collars. Foxes were monitored nightly for two weeks each month, with the goal of obtaining a minimum of 40 independent locations per animal throughout the course of the breeding season (January-June). These locations were used to calculate home range size using the Minimum Convex Polygon method and home range usage using the Harmonic Mean Interval method (White and Garrott 1990).

Thirty baited camera stations were placed on a 1 km grid throughout both study areas. Bait stations were equipped with a Kodak 110 m instamatic camera set to trigger mechanically when an animal took the bait. Bait consisted of a small bag filled with mixed cat food and canned mackerel set in a dish of oil to retain hydration. The numbers and locations of stations triggered by predators were used to obtain a relative index of abundance (control vs. exposed). A few recaptures were obtained from photographs of tagged foxes, suggesting that a mark-recapture estimate of fox abundance might be made from these data as well.

RESULTS

Noise Exposure:

Noise from aircraft in the exposed area was high. In 1992, the community noise monitors recorded

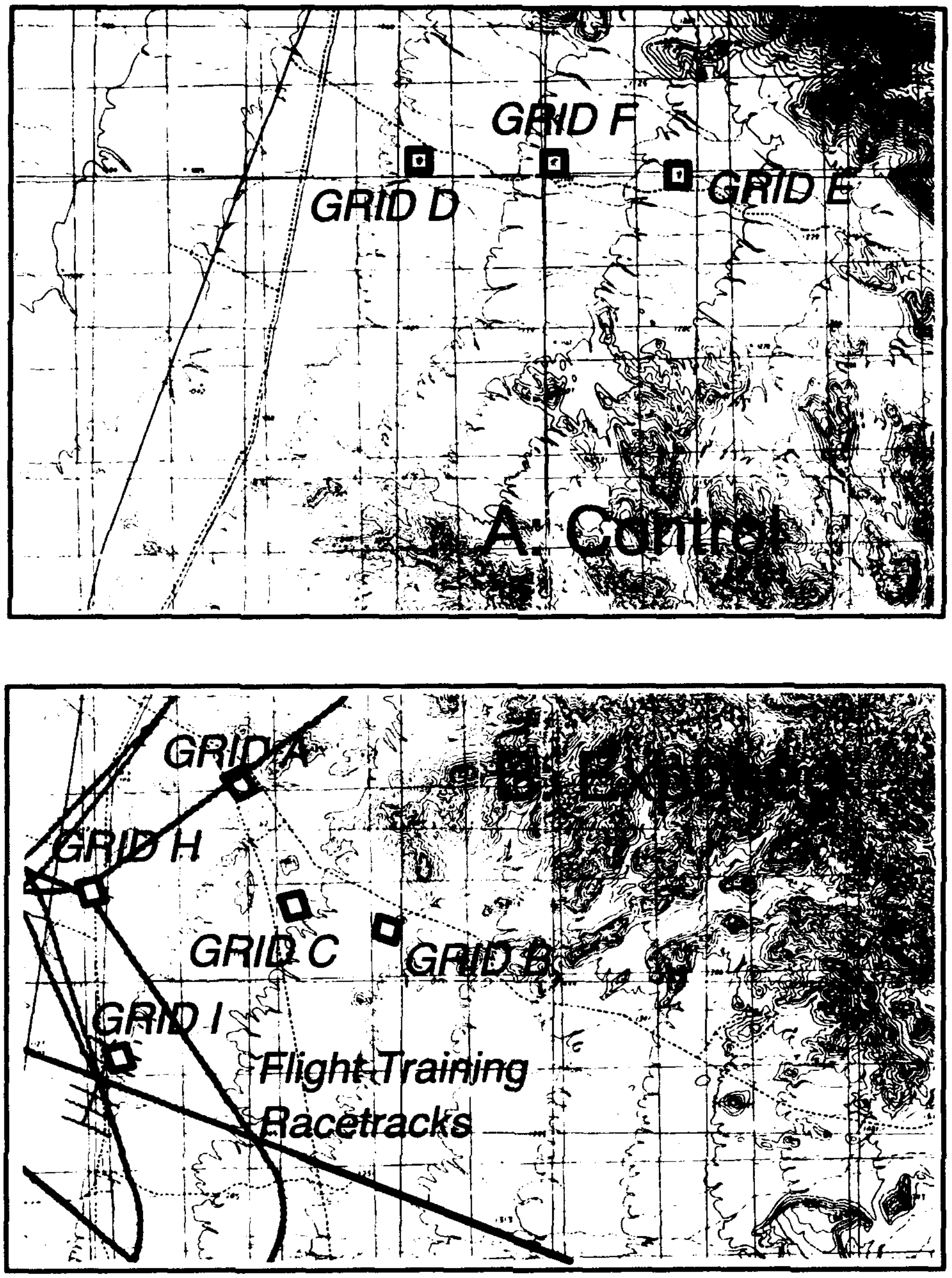

Figure 1: Location of flight training racetracks and small mammal survey grids.

21,780 events in 13,911 hours exceeding preset thresholds, for an average of 1.57 events per hour of monitoring time. Average daily event rates ranged from 0 on weekends to 167 events/day during intensive training exercises. Events averaged 15 sec in duration. There were large differences in the typical intensity of overflights at the monitoring sites; as expected the most intensely exposed sites lay under the training racetracks. In outlying areas, only 1-5% of events exceeded 100 dB ASEL (Figure 2). However, at the most intensely exposed site, over 40% of the 1585 events recorded in a 9 day period exceeded 100 dB.

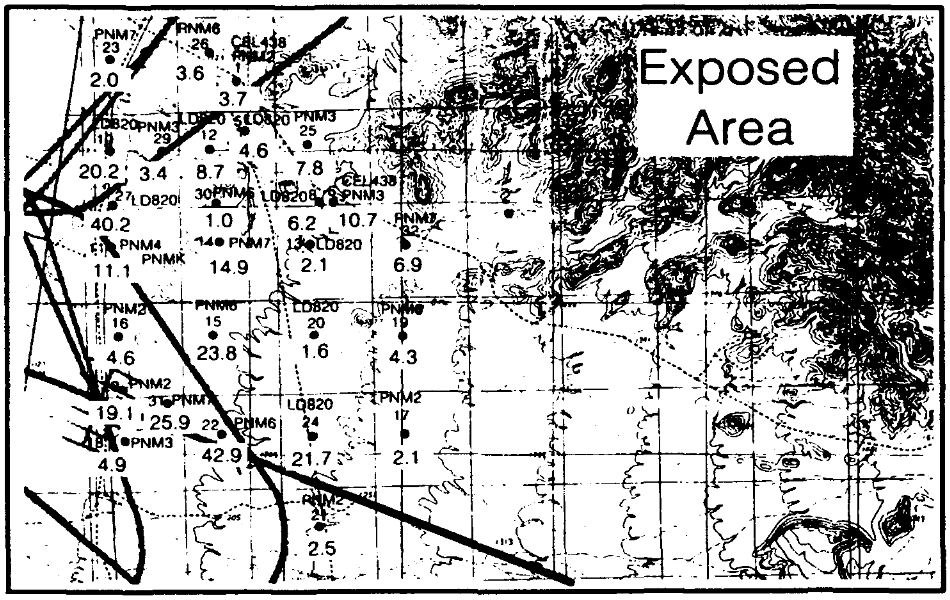

Figure 2: Percentage of events at each station that exceed 100 dB ASEL (relative to number > 80 dB MXFA)

Average hourly levels (Leq) in the absence of aircraft overflights ranged from 30-40 dB. Daytime overflights elevated these values to an average of 58-67 dB, an increase of around 30 dB. Nighttime overflights were less common, elevating hourly levels to an average of 43-46 dB, an increase of 10-15 dB. Duty cycles of aircraft noise were never high, however, ranging from 0.06% in the least exposed areas to 2-3% in the most exposed areas (measured as the % of seconds/day with aircraft noise).

Exposures in the control area were minimal. In 1359 hours of monitoring in 1993, 678 events exceeding 70 dB were recorded, or 0.49 events per hour (duty cycle 0.21%). The highest Lmax recorded was 98.5 dB, but the proportion of events exceeding 80 dB Lmax was never more than 0.07% and the proportion exceeding 95 dB was never more than 0.0034%. Exposures generally occurred when aircraft swung a little wider than typical during training circuits. Exposures in the control area elevated average hourly Leq values by less than 3 dB.

<u>Studies of Small Mammal Demography:</u>

Through July, 1992, a total trapping effort of 3,381 trap-nights was expended on the six study sites. During that time, a total of 1,080 captures were made on the six plots and 564 different individuals were captured, marked and released; . In descending order of abundance, rodent species captured were the Arizona pocket mouse (*Perognathus amplus*), Merriam's kangaroo rat (*Dipodomys merriami*), the desert pocket mouse (*Chaetodipus penicillatus*), the banner-tailed kangaroo rat (*Dipodomys spectabilis*), and the white-throated woodrat (*Neotoma albigula*).

The number of individual small mammals captured each month varied over the course of the season. The smaller species (*P. amplus* and *C. penicillatus*) hibernated during the winter months, declining as temperatures dropped in October and rising again as temperatures began to rise in March. The first peak in abundance occurred in May of 1992, following the spring rains, and a secondary peak occurred in September, following the summer monsoons (a second rainy period from June-August).

In 1992, the numbers of species present on the grids in each month did not vary substantially between exposed and control plots in any given month; none of the monthly comparisons of means for control vs. experimental groups were statistically significant (t-test, df=4; $p >> 0.05$). However, species diversity was consistently higher in the control area in all the months when small mammals were not hibernating. In most months, the number of Merriam's kangaroo rats in the control area was greater than in the exposed area as well. Unfortunately, the exposed study grids lay within the territories of one or more foxes that raided traps and kangaroo rats were very vulnerable to this form of predation based on remains found at the trap sites. Therefore, Merriam's kangaroo rats could have been suppressed artificially in the grids on the exposed area. In the winter of 1993 two of the study plots were moved out of the affected area and directly under the path of greatest exposures to aircraft (Figure 1). Diversity of vegetation was better matched at the new sites as well.

Data from 1993 are not complete as yet. The winter season was short. Warming began in January and numbers of small mammals rose rapidly thereafter. Small mammal abundance at these new sites could not be distinguished from the control grids, including the abundance of Merriam's kangaroo rats. Diversities were also indistinguishable. This suggests that differences in diversity and abundance observed in 1992 were a function of sampling bias. Differences in trappability, age and sex composition, recruitment, survivorship, and reproduction were not discovered.

Studies of Fox Demography, Home Range Usage, and Prey Preferences

Fox trapping successes were high from November until February, coincident with the hibernation period of small mammals, but declined precipitously as populations of small mammals began to rise. It is quite possible that they were not motivated to enter traps when an abundance of prey was available. Because trappabilities were highest in the first month of each breeding season, it is also possible that foxes were wary of traps after their first capture; most foxes were trapped only once (56%) and only 11% were captured more than twice. These results suggested that the abundance of foxes estimated using recaptures was likely to be biased.

A total of 16 foxes were captured in the exposed area from September of 1991 to June of 1993, 8 females and 8 males. Most were adults and 7 were tracked by radiotelemetry. A total of 13 foxes were trapped in the control area during the same period, 9 of which were tracked. Most of the trapped foxes were adults. Two foxes died in the control area and one in the exposed area during 1992 (57% of collared animals), a rate somewhat higher than that found in other areas where foxes have been studied. One fox died in the exposed area and one disappeared in the control area in 1993 (19% of collared foxes). The low rate in 1993 was most likely the consequence of the short

winter season.

Home range sizes of foxes in both areas were compared. They averaged 4.44 km^2 (se=0.52) in the exposed area and 3.90 km^2 (se=0.46) in the control area. The two averages did not differ significantly (t-test, df=14; $p >> 0.05$).

The abundance of foxes was minimally 16 individuals in 1992 and possibly as high as 35, based on mark-recapture statistics. The number of foxes estimated from home range sizes lay between these two values (22 foxes). Turnover rates were relatively low -- 11 of 17 foxes trapped in December of 1992 in the exposed area had been marked in the previous breeding season (65%). This suggests that most of the foxes that were trapped were established territory holders that retained their territories throughout the year.

Camera station surveys in 1993 revealed an important complicating factor, however. These surveys uncovered the presence of one or more gray foxes in the exposed area, where none were discovered in the control area. The gray fox(es) were detected at 7 of 19 camera stations in the exposed area, but none were photographed in the control area, even though the proportion of available habitat was similar. The gray fox(es) apparently displaced one kit fox, which moved to the control area halfway through the breeding season. Kit foxes were photographed at 5 camera stations in the control area, but only two stations in the exposed. There were also many fewer photographs of kit foxes collected in the exposed area (3 photos vs. 13). This suggests that, while kit foxes occupied the exposed area in equal numbers, they were displaced from the camera stations by gray foxes. It is possible that gray foxes also affected their home range usage.

DISCUSSION

Limited effort has been expended to determine the effects of aircraft noise on small mammals in the wild. The only previous effort measured populations of small mammals exposed to noise near the runway of a large airport. Feral mice (*Mus musculus*) at this site were exposed to noise from commercial aircraft taking off several hundred times per day. Noise exposure was not measured, but the mice were found to have enlarged adrenals that might have been attributable to aircraft noise (Chesser *et al.* 1961). However, mouse abundance did not differ relative to similar, but undisturbed, habitats. Ultrasonic noise, which rodents hear better than low frequency noise, has been used to eliminate rodents from granaries, but intense levels and continuous exposure are required, and the method is not always successful. This suggests that continuous intense exposure is required to produce detectable effects on small mammal abundance, and that effects on adrenals, while evidence of physiological adaptation to a stressor, does not provide evidence of distress or effects on the well-being of populations. Unfortunately, Chesser *et al.* did not look at age and sex specific differences in survivorship, recruitment, or emigration, which might have provided a more sensitive measure of effect.

The results of this study to date suggest that aircraft noise from military training activity does not affect the demography of small mammals on the BMGR. Differences in diversity and abundance were not significant in 1992 and disappeared once sources of study bias (foxes attacking rodents in traps, differences in vegetation diversity) were eliminated. Other measures, including trappability, proportions of individuals in breeding condition, survivorship and recruitment did not differ between the two areas. Future studies will be undertaken to determine whether physiological effects on hearing and adrenals can be uncovered.

The differences found in small mammal abundance between exposed and control areas in 1992

llustrate one of the most important problems in studying the effects of aircraft noise on animals. Effects, if present, are likely to be subtle by comparison with variability due to natural causes. Natural variability must be carefully monitored and controlled before any effects due to aircraft can be uncovered.

Effects on carnivores as a group have not been studied often. Fox home ranges overlapped both lightly traveled and intensely traveled portions of the exposed area. Successful dens were uncovered under the most intensely exposed portions. Further analysis will be required to determine whether foxes in the most heavily exposed areas used their home ranges differently, but at present there is little evidence that home ranges were affected by noise from aircraft. On the other hand, presence of natural competitors and predators (gray foxes) did apparently have an effect on kit foxes. Further analysis will be undertaken at the end of the program to determine whether subtle differences can be detected, such as a correlation between home range size and noise, number of alternate denning sites and noise, and gray fox distribution and noise.

The intense training activity on the BMGR is the worst exposure likely to be found due to military training activity in wilderness areas in the U.S.A. Training activity on long-range military training routes is lower, averaging 1-6 overflights per day (USAF unpub.) Unfortunately, it is not possible to say whether this exposure produces damage in any species, nor even to specify the best metric to use to predict damage. Future study effort should concentrate on the development of dose-response models similar to those used to mitigate noise damage in humans. At present, the only guidelines available are those used for humans (e.g. U.S. CHABA guidelines). Based on these guidelines, increases in average noise levels on the BMGR are not high by comparison with noise near airports or in cities. The average hourly and daily levels (Leq) detected during this study are at the borderline of what would be considered annoying by humans (55-70 dB), and well below levels required to produce significant hearing loss or physiological damage (continuous exposure at 85 dB and upward). This may explain why evidence of effect has not as yet been uncovered. Although intense behavioral responses are produced by aircraft noise in naive kit foxes *(Bowles and Francine unpub.)*, there is no evidence that habituated foxes in the exposed area experience any negative effects. This suggests that the effects of noise, if present, are subtle, and that great caution should be used in interpreting short-term responses as evidence of stress (in the sense of distress). In free-ranging animals, the results of stress, such as effects on reproduction, habitat use, general health, and longevity, must be measured directly.

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THE EFFECTS OF LOW-ALTITUDE JET AIRCRAFT ON DESERT UNGULATES

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Abstract.--We evaluated the effects of simulated low-altitude jet aircraft noise on the heart rate (HR) of 6 captive desert mule deer (*Odocoileus hemionus crooki*) and 5 mountain sheep (*Ovis canadensis mexicana*). Following this experiment we monitored the HR of 5 mountain sheep in a 3.2 km^2enclosure as F-16 jet aircraft flew over the enclosure. In the first study, conducted at the University of Arizona, Tucson, from May 1991 to April 1992, penned animals were exposed to simulated noise from jet aircraft (range = 92-112 decibels [dB] during 3 seasons (n = 112 overflights/season). We compared HRs during simulated overflights to HRs obtained prior to and after treatments. We documented differences among HRs for animals, noise level, and number of overflights among seasons. All animals became habituated to sounds of low-altitude aircraft. Although HRs increased during overflights, HRs returned to normal in $\leq$ 2 minutes. Results were similar for the second part of the study when we monitored the HR of 5 mountain sheep from May 1991 to March 1992 in a 3.2 km^2 enclosure in Nevada. We established 3 1-month periods when F-16 aircraft flew over the enclosure. We recorded HR 15 minutes prior to, during, and after overflights. Heart rate increased above normal in 21 of 242 overflights, however, they returned to normal within 2 minutes. We concluded that F-16 aircraft flying over mountain sheep do not create increases in HR that are detrimental to mountain sheep.

Recently, wildlife managers expressed concern about the influence of noise from low-altitutde jet aircraft on ungulate populations (Asherin and Gladwin 1988). The effects of noise from low-altitude subsonic jet-aircraft have not been studied extensively. However, studies have demonstrated that wild ungulates react in various ways to fixed-wing aircraft and helicopters flying < 152 m above ground level. Reindeer (*Rangifer tarandus*) exhibited panic responses (Calef et al. 1976); mountain sheep were alerted (Krausman and Hervert 1983), altered foraging activity (Stockwell et al. 1991), moved more, changed home-range polygons (Bleich et al. 1990), and increased HR (MacArthur et al. 1979, 1982); and desert mule deer changed habitat (Krausman et al. 1986). Harrington and Veitch (1991) reported low jet overpasses "... indicated an initial startle response but otherwise brief overt reaction by woodland caribou (*R. tarandus*) on late-winter alpine tundra habitats."

Animals react differently to sound intensity, duration (Ames and Arehart 1972, Borg 1981), and direction (Tyler 1991). However,habituation to intermittent sounds $\geq$ 75 dB has been demonstrated with rodents (Borg 1981), domestic sheep (Ames and Arehart 1972), and elk (*Cervus elaphus*) (Espmark and Langvatn 1985).

The unknown effects of auditory and visual stimuli from jet-aircraft may be a potential threat to wild ungulate populations. How animals respond to aircraft noise can be important in management decisions about United States Air Force use of air space and wildlife subjected to overflights. We measured the HR of desert mule deer and mountain

sheep subjected to simulated and actual jet-aircraft overflights to determine if low-altitude aircraft noise creates a chronic increase in HR.

Fluctuations in HR are a sensitive indicator of responses to an array of stimuli including noise (MacArthur et al. 1979, 1982; Nilssen et al. 1984; Fancy and White 1986) in ungulates. Heart rate varies with level, intensity, duration, and probably frequency of auditory stimuli (Ames and Arehart 1972).

This study was funded by the United States Air Force and the University of Arizona, Tucson, Arizona. R. C. Etchberger and R. C. Kull, Jr. reviewed the manuscript.

STUDY AREA

This study was conducted in the laboratory and field. The laboratory study was conducted on the University of Arizona Agricultural Research Center, Tucson, Arizona. We used 5 captive-born mountain sheep (3M, 2F) and 6 captive-born desert mule deer (6M). Animals were enclosed in 6-X-15 m pens (2 animals/pen). Pens were designed to decrease all uncontrolled noise to an average sound pressure level of 45 dB. An observation room that housed noise simulation equipment was adjacent to the pens. The speaker to simulate aircraft noise was secured at a 41.5° angle directed toward the pens on top of a 6-m scaffold 1 m south of the pens.

We conducted the field study at the north end of the Desert National Wildlife Refuge (DNWR), Nevada. We constructed a 3.2 km^2 enclosure bounded by a 2.4 m-high fence that included most habitats available to sheep in the DNWR. Further details about the laboratory and field study areas are reported by Krausman et al. (1993a,b), respectively.

METHODS

Laboratory Study

We placed deer and sheep in the pens and measured HR with internal monitors (40 mm X 65 mm; 170g) (J. Stuart Enterprises, Oceanside, Calif.) following surgical procedures of Bunch et al. (1989). Accuracy of HR monitors was compared to transmitted HR with ECG results (Hewlett-Packard Model 7830A) (Pauley et al. 1979, Cassirer et al. 1988) during surgery. After surgery animals were in the experimental pens for ≥ 4 weeks prior to experimentation to recover from surgery and become habituated to the pens.

Low-altitude aircraft noise was simulated with a digital sound system (Chavez et al. 1989). Simulated noise was from B-1B and F-4D aircraft with onset rates from 10.1 to 45.6 dB/second and maximum "A" weighted levels from 92.5 to 112.2 dB. The pens, with 2 conspecifics/pen, exposed animals to 5 different noise levels during each overflight depending on their location in the pen.

The experiment was conducted in 3 periods: summer (12 May - 9 Aug 1990), late summer (13 Aug - 12 Oct 1990), and spring (4 Feb - 5 Apr 1991). The experimental treatment exposed animals to 1 simulation event (overflight)/day for days 1-7 and 22-28, and 7 simulation events/day for days 8-21 of the treatment period. We randomly selected simulation events, times, and animals to be monitored during diurnal hours. In spring 1 mountain sheep and 2 deer were replaced with animals that had not been exposed to simulations.

We recorded the HR of animals before, during, and after each simulated overflight. The HRs were analyzed using a repeated measures analysis of variance (MANOVA) (PROC GLM [SAS Inst., Inc. 1985:433]). We used 5 measurements of HR for each event: 1 minute before the overflight (hr1), the actual overflight (hr2), and the first, second, and third minute after each overflight; hr 3, hr4, and hr5, respectively. We used Wilk's lambda (PROC GLM [SAS Inst., Inc. 1985:433]) to compare HR among individuals, types of overflights, and noise level exposure based on the calibrated area of the pen in which animals were located. The criteria for rejection of a statistical test was $P < 0.05$.

Field Study

This study was conducted from May 1990 to May 1992 in 2 parts. From May 1990 to May 1991 mountain sheep were placed in the enclosure for habituation. Experimentation (overflights) occurred from May 1991 to May 1992.

After the 3.2 km^2 enclosure was completed we calibrated the sound field produced by the noise generated throughout the area with F-16 aircraft flying 125 m above ground level, with 90% power settings, and a flight course ± 63 m of the prescribed flight path (R. E. Nugent, and D. S. Barber, Site noise calibration for the desert bighorn sheep study, Acentech, Inc., Calif., Rep. 38, 15 + pp., 1990).

We captured 19 mountain sheep in May 1990 and 1991 (6M, 13F) with a net gun (Krausman et al. 1985) from the DNWR. One female was implanted with a HR monitor, following procedures outlined in the laboratory study, during the first year to determine if HR could be collected in the field. We were able to record the HR of desert bighorn sheep from ≥ 1 km, so in 1991 we captured 5 more sheep and implanted them with HR monitors also; 1 female died from unknown causes leaving 3 females and 1 male with HR monitors.

During the treatment we scheduled F-16 aircraft from Nellis Air Force Base, Nevada to fly a predetermined route over the enclosure in 3 periods: 24 May - 27 July 1991; 20 September - 20 November 1991, and 4 February - 2 April 1992. Aircraft were scheduled randomly to fly over the enclosure during diurnal hours in the middle 4 weeks of each period. During the first week 1 aircraft/day was scheduled to fly over the area. The following 14 days ≤ 7 aircraft/day flew over the enclosure followed by 1 aircraft/day during the last week. Aircraft were not scheduled to fly on weekends.

We located sheep with HR monitors and recorded their behavior, HR, and locations 15 minutes prior to, during, and 15 minutes after overflights. When possible we contrasted habitat use, behavior, and HR of sheep we observed prior to, during, and after overflights. Further details about the laboratory and field study methods are reported by Krausman et al. (1993a, b), respectively.

RESULTS

Laboratory Study

No deaths or injuries to animals resulted from the surgical procedures or experimental treatments. Heart rate transmitter failures, due to lead breakage and body fluid leakage into transmitters (Wallace et al. 1992) during late summer reduced HR recordings.

Examination of HR responses during the treatment periods showed HRs returned to the rates exhibited before the simulation events (Table 1) in ≤ 2.0 minutes (Fig. 1) after the overflight. Analyses with repeated measures (ANOVA) showed significant differences among individual animals. In summer, data came from 5 animals whose HR transmitters worked through the season. Measures for hr2, hr4, and hr5 differed among animals (F = 2.82, 4.02, 3.70; 3,62 df; P = 0.0463, 0.0112, and 0.0162, respectively). Late summer problems with HR transmitter failures provided sufficient observations for only 1 mule deer. Therefore, differences among individuals could not be tested. In spring, data were collected for 8 animals. Individual differences were significant (F = 5.99, 3.10, 6.31; 6,12 df; P = 0.0043, 0.0445, 0.0034) for hr3, hr4, and hr5, respectively.

Wilk's lambda's (L); multivariate tests of interaction effects between time, animal, flight, and area, helped isolate the sources of variation in HRs. For summer, time, time X flight, and time X area effects were significant (L) = 0.66; 4 df, 59; P < 0.0001; L = 0.52; 24 df, 207; P = 0.0199; and L = 0.71; 12 df, 156; P = 0.0496, respectively). Interactions including animal effects were not significant (P > 0.05). In other words, the rate of change between HR measurements was the same for all animals. However, the type of simulation event (flight) and the area in the pen did affect animals' HRs. Significant flight effects (P ≤ 0.05) were apparent only in hr2 measures (e.g., right at the overflight). Animals

Table 1. Mean heart rate (beats/min) for active (e.g., standing, running, foraging) and inactive (e.g., bedded) mountain sheep and desert mule deer prior to exposure to noise (92.5-112.2 dB) from simulated jet aircraft, University of Arizona, Tucson, 1990-1991.

	Mountain sheep		Desert mule deer	
12 May-9 Aug 1990	Active	Inactive	Active	Inactive
$\bar{x}$	66.61	52.63	55.77	44.12
Range	40-142	32-112	32-104	32-112
SE	0.93	0.37	1.01	0.49
No. animals	4	4	4	4
No. obs	464	826	122	659
13 Aug - 12 Oct 1990				
$\bar{x}$	73.25	68.45	64.35	54.54
Range	52-112	40-100	40-104	40-80
SE	1.71	1.04	1.40	0.46
No. animals	3	3	3	3
No. obs	64	161	68	277
4 Feb - 5 Apr 1991				
$\bar{x}$	60.35	48.93	59.40	46.32
Range	32-128	32-84	32-136	32-68
SE	0.95	0.49	1.33	0.38
No. animals	4	4	4	4
No. obs	298	380	241	365

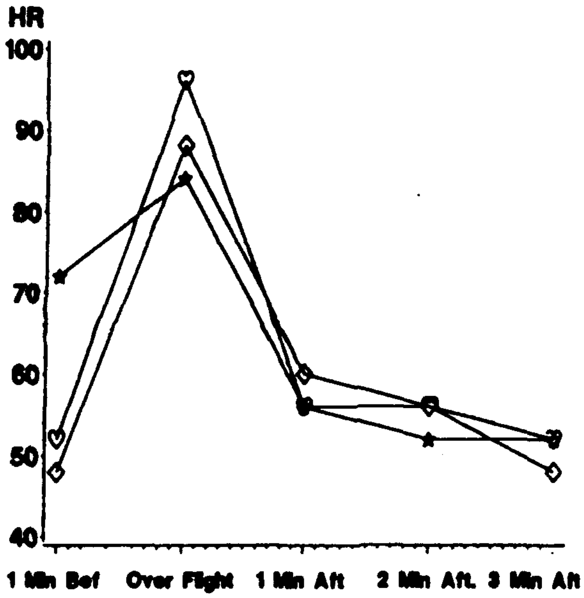

Figure 1 : A typical heart rate (HR) reponse to simulated noise from jet aircraft . Heart rate of an adult mountain sheep 1 minute (MIN) before (BEF), during and 1,2, and 3 min, after (AFT) a simulated overflight of an F-4D aircraft (98.8 - 108.8dB) . This experiment was conducted during the summer (12 May - 9 Aug) period in Tucson, Arizona . The sheep exposed to these 3 overflights (first exposure = diamonds, second exposure = hearts, third exposure = stars) during diurnal hours and each flight was separated from the others by 1 hour .

responded more to the higher sound level created by F-4D flights (89.2-107.3 dBA) than to B1-B flights (83-106 dBA). Area effects were significant ($P \leq 0.05$) from hr2 through hr5 with consistently greater response in pen area 2 (84.5-108.2 dB) than from pen areas 4 (76.5-100.2 dB) and 5 (72.5-96.2 dB).

Data for late summer was based only on 1 deer and only in zones 4 and 5. There were no significant responses ($P \geq 0.05$) to differences in times, flights, or areas.

Wilk's lambda's for spring showed only the time X area and time X animal X flight effects were responsible for the variation ($L = 0.05$; 8 df, 18; $P = 0.0002$, and $L = 0.002$; 60 df, 37; $P = 0.005$, respectively). Heart rates were higher in areas 2 (84.5-108.2 dB) and 3 (80.5-104.2 dB) than area4 (76.5-100.2 dB). The 3-way interaction confounds animal and flight effects. However, significant HR differences ($P < 0.05$) were most often greater with animals 004, 005, 012, and 014, and less for the noise created by the B1-B flying at 317 m (offset = 312 m, speed = 578 knots, onset = 10.7 dB/sec, $L_{eq} = 92.5$, $L_{max} = 101.0$). The responses to this aircraft were consistently less than all but flights of the F-4D at 33 m (offset = 620 m, speed = 534 knots, onset = 10.1 dB/sec, $L_{eq} = 83.8$, $L_{max} = 92.5$) and 465 m (offset = 11 m, speed = 561 knots, onset = 20.2 dB/sec, $L_{eq} = 94.9$, $L_{max} = 107.2$). Animals 005, 012, and 014 were naive and added to the experiment for season 3.

Field Study

Enclosure Calibration.--The F-16 aircraft created 5 noise zones when properly flying along the flight path. The highest sound level (106-110 dB) was restricted to a small patch at the top of the ridge. The remainder of the ridge received 100-105 dB. This zone was surrounded by a broader zone of 95-100 dB followed by a 90-95 dB zone. The desert flats were farthest from the flight path and received 85-90 dB. The ambient sound environment that sheep were accustomed to was 65 dB 3 seconds prior to overflights.

Overflights.--We obtained 111, 57, and 74 overflights in periods 1, 2, and 3, respectively. We were not able to examine the response of sheep to all overflights. Only 1 sheep was observed/person/overflight and ≤ 2 biologists/overflights made observations. Sheep were not always located and sometimes when locations were made the sheep were in a position where the HR signals were unclear. Also the HR monitor for a female failed in the middle of the first treatment period. We obtained overflight data for 1 male and 2 females. We recorded 45 reactions of male 4270 during periods 1 and 2, 31 reactions of female 5010 during period 1 and 73 reactions of female 4322 during periods 1, 2, and 3.

Heart Rates and Overflights.--We compared the recorded HRs for all 4 instrumented mountain sheep in the 24 May-27 July 1991 period, and between the male and female 4322 in the 29 September to 20 November 1991 period with a one-way ANOVA. There was a significant difference ($P < 0.001$) among sheep so we examined each separately.

Adult male 4270: The HR of this male was significantly higher ($P < 0.001$) prior to overflights in both periods than after the overflight occurred. However, all values were within the range of HR values for mountain sheep reported in various activities prior to being exposed to any subsonic noise (Table 2). During period 1 aircraft flew over the male 27 times but his HR never exceeded normal levels (Table 2). During period 2 jet aircraft caused the HR to exceed normal levels 2 times, while he was standing. In both cases the HR returned to normal within 60 seconds.

Adult female 5010: The HR of this female was significantly higher ($P < 0.001$) prior to overflights than after overflights in period 1. As with the male, all values were within the range of HR values reported for mountain sheep in various activities prior to being exposed to any subsonic noise (Table 2). We recorded her HR 31 times as aircraft flew above her during period 1. On 1 occasion, while she was standing, her HR exceeded normal (Table 2) but returned to normal in < 60 seconds.

Adult female 4322: The HR of this female was significantly higher ($P < 0.001$) prior to overflights in periods 1 and 2 compared to after the flights. In the third

Table 2. Mean heart rates (beats/min) for mountain sheep in various activities prior to any constant exposure to subsonic noise (Krausman et al. 1993).

Heart rate	Walk	Bedded	Standing	Running	Forage
$\bar{x}$	66.4	50.4	60.0	107.5	60.5
Range	44-116	32-76	44-88	60-132	40-88
SE	1.62	0.33	0.53	5.01	0.68
No. sheep	4	4	4	3	4
No. obs	73	501	306	15	143

period the overall HR was higher after overflights compared to HRs prior to overflights. Again, all HRs were within the normal range for each activity (Table 2). During period 1 we obtained 27 observations of this female as aircraft flew overhead. On 1 occasion, while she was standing, her HR increased beyond normal limits but we were not able to obtain further HRs to determine how long it took for the HR to return to normal.

In the second period we obtained 20 observations as aircraft flew overhead. Only once, while she was standing, did her HR increase beyond normal limits but it returned to normal in < 60 seconds.

In the third period we recorded 26 HRs as aircraft flew overhead. Her HR increased above normal 16 times while she was standing but returned to normal in ≤ 60 seconds 14 times and in ≤ 120 seconds 2 times. During the third period this female had a lamb and responded more to overflights. Females with lambs are more vigilant than those without lambs (R. C. Etchberger, Univ. Arizona, and P. R. Krausman, unpubl. data) and more alerted to disturbances.

Overall we observed F-16 jets fly over mountain sheep 149 times and documented responses 124 times (83%). Heart rates exceeded normal levels only 21 times (16.9%) and only for short periods.

We examined the statistical differences in HR prior to and after the F-16 overflights with stepwise multiple regression. The sound zone the sheep were in and the elapsed time from the overflight did not explain enough of the variation to even be included in the regression. The change in HR could not be explained by habitat used, activity (r^2 = 0.34), or the quality of the flight (r^2 = 0.35). The change in HR can be explained best by the behaviors the animals were engaged in.

DISCUSSION

Our studies were unique for ≥ 2 reasons. First, animals were exposed to known and measured noise levels. Second, the exposure to noise from low-flying aircraft was controlled.

The results from the laboratory and field studies were similar. The HRs of animals increased as noise was generated or aircraft flew over animals but HR returned to normal levels in ≤ 2.0 minutes. This is consistent with data from Harris (1943), MacArthur et al. (1979, 1982), Espmark and Langvatn (1985), and Workman et al. (1992). When excited or alarmed, animals have higher HRs than normally exhibited for the same behaviors (Jacobsen et al. 1981). Our data follow this trend. MacArthur et al. (1979) described mountain sheep resting and walking HRs as 43.3-62.5 and 77.0-92.1 beats/minute, respectively. This is consistent with Harlow et al. (1987), Coates et al. (1990), and the mean HRs for sheep bedded and walking in this study.

Wildlife and domestic species can habituate to human-related disturbances (Dorrance et al. 1975, Espmark and Langvatn 1985, Yarmoloy et al. 1988) over time. Although few have investigated the effects of military low-altitude aircraft on animals Fletcher (1988) cautioned that aircraft noise exposure may influence animals. However, Harrington and Veitch (1991) reported the greatest impact of low-level flying jet aircraft

on caribou will be due to the startle reactions caused by the loud and sudden noise of low, direct overflights. They could not demonstrate other detrimental changes (e.g., influences to the energy budget).

We did not find that noise from low flying jet aircraft had any detrimental influence on the HR of desert mule deer or mountain sheep. Other responses (e.g., behavior, habitat use, movement) are reported by Krausman et al. (1993a,b).

Krausman et al. (1993a) stated that the long-term effects of low altitude aircraft and related noise on productivity and recruitment is information that is important in determining how these stimuli influence population dynamics. Although our study was not designed to study theses factors we obtained information that suggested overflights were not detrimental to productivity and recruitment. During the field study, productivity and recruitment exceeded 75% in both years; this was nearly 2 times higher than free-ranging populations in the DNWR (D. Delaney, NDW, pers. commun.). When the project terminated the enclosure was removed and all animals were alive.

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BEHAVIORAL EFFECTS OF JET AIRCRAFT ON CARIBOU IN ALASKA

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ABSTRACT

We evaluated the behavioral responses of free-ranging caribou (*Rangifer tarandus)* to low-altitude subsonic overflights by military jet aircraft. Overflights were conducted during three sampling periods in 1991: late winter (April), the post-calving period (June), and the insect season (July-August). Observers on the ground were positioned to direct the overflights and record caribou responses. Sound Exposure Levels (SEL) resulting from overflights were measured using prototype "Animal Noise Monitors" mounted on individual caribou or were modeled based on the proximity of the aircraft to the animals. During the three sampling periods, we recorded the reactions of 268 groups of caribou to 159 overflights by A-10 (n = 94), F-15 (n = 61), and F-16 (n = 4) jet aircraft. The mean slant distance (i.e., line-of-sight distance from the aircraft to the caribou) for all overflights was 756 m (SE = 181), and the estimated mean SEL for caribou under observation during all overflights was 98 dBA (SE = 0.7; maximum = 127). Approximately 50% of the caribou showed some degree of overt behavioral reaction to overflights, but only 13% of the overflights caused animals to move. There was no relationship between SEL and the duration of reactions (R^2 = 0.0003), or between SEL and the distance moved (R^2 = 0.02) by caribou in response to overflights. Activity budgets were compared between caribou that had been overflown recently (i.e., within the previous 15-min period) and caribou that had not been overflown recently; no differences were evident in late winter, but during post-calving and the insect season, overflown animals spent less time lying and more time either feeding (post-calving) or walking (insect season). Daily distance traveled was compared for animals that had not been overflown during the previous 24-h period and animals that had been overflown; distance traveled did not differ during late winter and the insect season, but treatment caribou traveled farther than did control caribou during post-calving. Overall, behavioral impacts were mild, although female caribou with calves reacted to overflights by jet aircraft by lying less and moving more, especially during post-calving (June). Females with newborn calves appeared to be less tolerant of aircraft disturbance than were caribou during other times of the year, and the daily movement data suggest caribou with newborn calves were moving away from disturbed areas. These results are consistent with other studies of the behavioral responses of caribou to disturbance. More detailed predictions of energetic and demographic consequences of repeated overflights currently are being developed, using a caribou energetics model.

INTRODUCTION

Concern about the effects of low-altitude, subsonic overflights by military jet aircraft on wildlife prompted the U.S. Air Force (USAF) to develop a research program to investigate impacts on wild ungulate species. Barren-ground caribou (*Rangifer tarandus granti*) from the Delta Herd in Interior Alaska were selected for study because detailed energetics models were available for this species and because this herd occurs near Eielson Air Force Base. The goals of the research program are to

quantify behavioral responses of caribou to low-altitude, subsonic overflights by jet aircraft and to incorporate these findings into a model that can predict the energetic and demographic consequences of repeated overflights. The field research program had three specific objectives: 1) measure noise levels experienced by caribou overflown at low-altitudes by jet aircraft; 2) evaluate the behavioral reactions of caribou to these overflights; and 3) compare movements of caribou exposed to overflights with those of animals that were not exposed to overflights.

METHODS

Sampling was conducted during three separate one-week periods in 1991: late winter (April), post-calving (June), and the insect season (July-August). The locations of study areas differed slightly among sampling periods because of the seasonal movements of caribou, but all were located on the north side of the central Alaska Range (between 63°35' and 64°14' N latitude and 146°14' and 148° 34' W longitude).

Prior to data collection in each sampling period, it was necessary to capture and instrument 10 female caribou with radio-collars and noise monitors. We selected two areas for collaring, at least 16 km apart, to serve as treatment (i.e., with overflights) and control (i.e., without overflights) areas. Five animals were captured in each area, and each was instrumented with a *Wildlink* collar (St. Paul, MN) that had a VHF radio transmitter and an activity counter (Kitchens *et al.*, in press). The five animals in the treatment area also were outfitted with Animal Noise Monitors (ANMs; see details below).

Jet aircraft overflights were conducted along specific flight paths requested by biologists communicating to the pilots through a forward air controller. We attempted to have jets make direct overpasses of caribou at 33 m above ground level with "high" or "full power" settings, but substantial variability in the precision of the overflights occurred. Pilots were instructed to maintain at least 5-min intervals between multiple overflights. An overflight consisted of 1-3 aircraft.

SOUND EXPOSURE

Prototype ANMs were deployed on five caribou during the late winter and post-calving sampling periods and on four caribou during the insect season. ANMs were programmed to record noise exposures that exceeded 85 dBA for more than 2 seconds and to calculate several acoustical parameters. We used the single-event Sound Exposure Level (SEL) for our analyses. SEL is a measure of the total amount of acoustical energy generated during an event and is calculated by integrating both the amplitude and the duration of the event.

For each overflight, we used direct measurements from ANMs, when available, to assign SELs to the groups of caribou that contained the animals equipped with ANMs. For groups of caribou for which noise measurements from ANMs were not available, we estimated SEL using the *OMEGA* 14.6 Aircraft Noise Prediction Program developed by the University of Dayton Research Institute (Dayton, OH, USA).

BEHAVIORAL RESPONSES

Instantaneous Reactions—For each overflight, we counted the number of caribou in each group that showed no overt behavioral response, the number that became alert, the number that stood up from a lying position, and the number that moved in response to the jet aircraft. We also recorded the duration of the reactions and the distances traveled by animals that moved. The duration of a

disturbance event was measured by assessing the behavior of the animal exhibiting the strongest reaction in the group under observation. We recognized alert postures, walking (if initiated by the overflight), and running as disturbed behaviors; a reaction was considered to continue until all members of the group had ceased disturbed behaviors and resumed undisturbed behaviors (e.g., feeding).

We compared instantaneous reactions by aircraft type and by season using multiple analysis of variance (MANOVA) after transforming the data with the arcsine function (Steel and Torrie 1980). To examine the relationship between the decibel level of overflights and the instantaneous reactions of caribou, we used linear regression models to test whether the duration of reactions or distance moved varied as a function of SEL.

Activity Budgets—To quantify activity, we scan-sampled (Altmann 1974) the entire group of caribou under observation at 5-minute intervals, using six activity categories: feed, lie, stand, walk, alert, and run. Activity budgets were derived by first classifying each scan as either disturbed (≥ 1 overflight during previous 15-min period) or undisturbed (no overflights during previous 15-min period) and then calculating the percentage of animals engaged in each activity category. We used MANOVA to compare activity budgets for disturbed and undisturbed caribou groups by season after transforming the data with an arcsine-square root function (Steel and Torrie 1980).

Movements—The locations of all instrumented caribou were recorded at least once daily (twice on days of overflights) using radio telemetry from a fixed-wing airplane. All locations were plotted on study area maps and then were digitized with a Geographical Information System (GIS). Daily distances moved were calculated for each animal using GIS. We then determined whether an individual animal had been overflown on a particular day and categorized each day as a treatment day (≥ 1 overflight during previous 24-h period) or a control day (no overflights during previous 24-h period) for each animal. Within each sampling period, distances traveled were ranked and analyzed using analysis of variance (ANOVA).

RESULTS

SOUND EXPOSURE

Caribou were exposed to a total of 159 overflights by jet aircraft during the three sampling periods. Of these overflights, 94 were by A-10s, 61 were by F-15s, and 4 were by F-16s. During the late winter and post-calving sampling periods, only A-10 and F-15 aircraft were available. During the insect season, A-10s, F-15s, and F-16s were used. We often were able to observe several groups simultaneously; therefore, 268 groups of caribou were observed during the 159 overflights.

The mean slant distance (i.e., the line-of-sight distance between the aircraft and the caribou) for all overflights was 756 m (Table 1). A-10s were able to provide the closest overflights (mean slant distance = 457 m), followed by F-15s (mean = 1197 m), and F-16s (mean = 1647 m). A-10s also were the slowest of the three aircraft, with airspeed averaging 502 km/h, whereas F-15s averaged 642 km/h, and F-16s averaged 806 km/h (Table 1).

SELs were measured or estimated for each overflight and ranged from 46 to 127 dBA; the maximum noise exposure was produced by an F-15 flying at a slant distance of 106 m from the caribou. The mean SEL for all 159 overflights was 98 dBA (Table 1). F-15s produced the greatest SELs (mean = 103 dBA), followed by F-16s (mean = 96 dBA) and A-10s (mean = 95 dBA).

Table 1. Flight characteristics and estimated Sound Exposure Levels (SEL) of low-altitude overflights of caribou by military jet aircraft in Alaska, 1991.

		Slant Distance (m)		Airspeed (km/h)		SEL (dBA)		
Aircraft	Season	Mean	SE	Mean	SE	Mean	SE	*n*
A-10	Late winter	375	28.4	470	3.8	99	1.1	77
	Post-calving	448	55.0	530	7.8	94	1.0	66
	Insect	749	221.9	526	12.0	90	2.5	24
	All	457	101.8	501	7.9	95	1.5	167
F-15	Late winter	538	76.4	659	23.6	106	2.3	28
	Post-calving	1606	330.5	560	50.4	96	1.1	27
	Insect	1414	308.3	693	8.9	105	2.0	34
	All	1197	238.4	642	27.6	103	1.8	89
F-16	Insect	1647	244.7	807	22.0	96	3.0	12
All		756	180.7	562	18.3	98	1.8	268

BEHAVIORAL RESPONSES

Instantaneous Reactions—For all overflights, 49% of the caribou showed no overt behavioral response, 31% became alert, 6% stood up from a lying posture, and 13% moved in response to the jets. Responses to F-15s generally were stronger than those recorded for A-10s and F-16s; however, only the percentage of groups showing no response was significantly ($p \leq 0.05$) different among types of aircraft (Fig. 1a). No differences were detected in reactions among sampling periods (Fig. 1b). Linear regression models indicated very low correspondence between SEL and both of the response variables (SEL vs. duration of reaction, $R^2 = 0.0003$; SEL vs. distance moved, $R^2 = 0.02$).

Activity Budgets—Activity budgets calculated for groups of caribou that had not been overflown during the previous 15-minute period were compared with those of animals that had been overflown. During late winter, no significant differences were found between the activity budgets of caribou that had been overflown recently and caribou that had not been overflown (Fig. 2). During post-calving, however, there were significant ($p \leq 0.05$) differences between the two periods in the pe.centage of time spent feeding and resting; caribou that were overflown recently spent more time feeding and less time lying than did caribou that had not been overflown. Similarly, during the insect season, caribou that had been overflown recently spent less time lying and more time walking than did caribou that had not been overflown (Fig. 2).

Movements—Daily distance traveled was compared for animals that had been overflown during the previous 24-h period (treatment) and animals that had not been overflown (control) (Table 2). Distances traveled by treatment and control animals during late winter and the insect season did not differ, but treatment animals traveled significantly ($p \leq 0.05$) farther than control animals during post-calving .

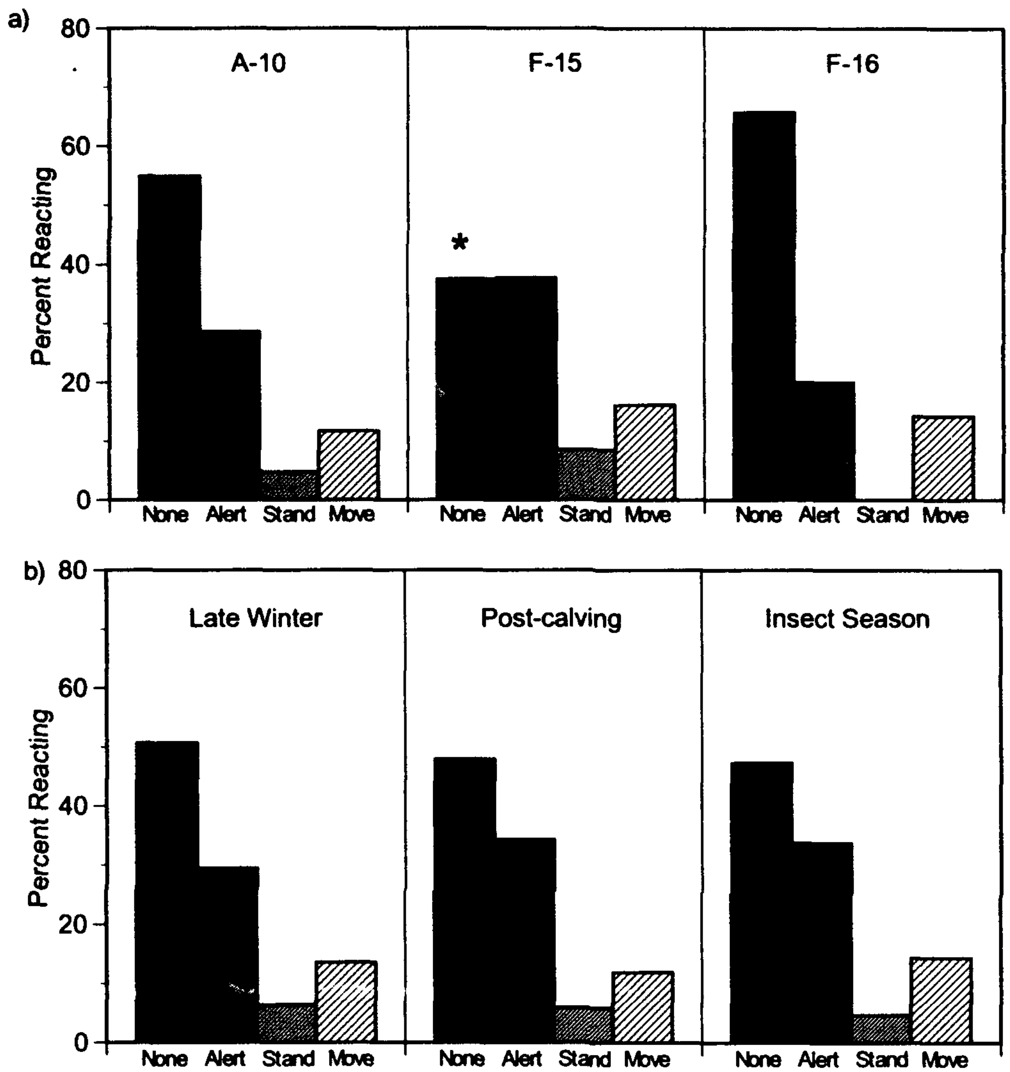

Fig. 1. Percentage of caribou exhibiting various instantaneous reactions to low-altitude overflights by jet aircraft in Alaska during 1991 by (a) aircraft type and by (b) season. Significant ($p \leq 0.05$) differences for each reaction category by aircraft type and by season are noted with an asterisk.

DISCUSSION

In interpreting our results it is important to note that the caribou we observed are exposed frequently to civilian aircraft and to jets during routine military exercises. Davis *et al.* (1985) characterized the Delta Herd as the most highly disturbed caribou herd in Alaska. Thus, we clearly were dealing with a herd that either has habituated or, at least, has had the opportunity to habituate to aircraft disturbance.

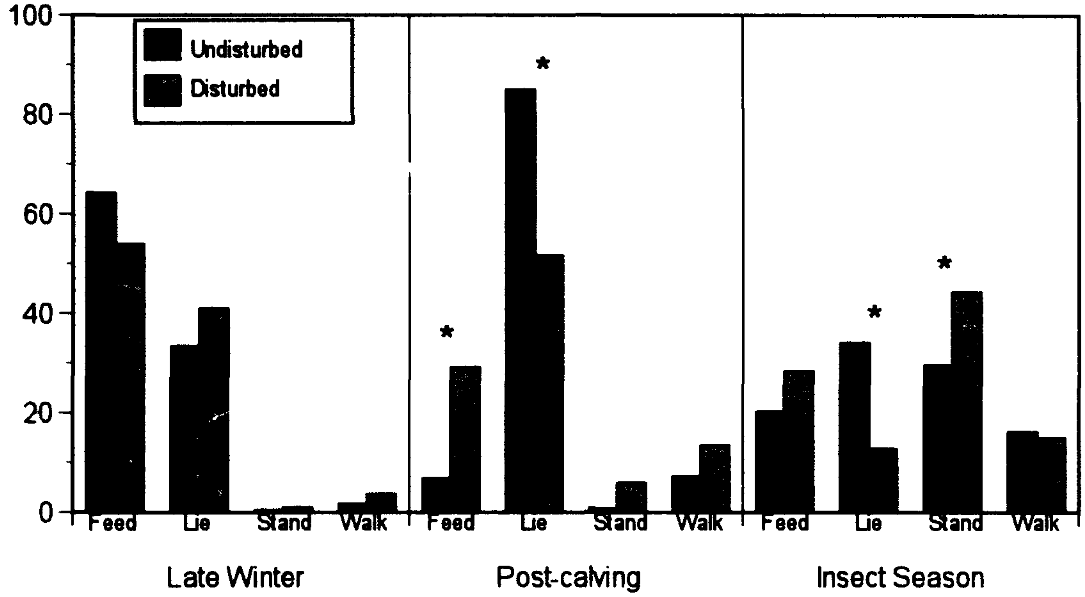

Fig 2. Seasonal comparison of activity budgets of caribou that had not been overflown by military jet aircraft during the previous 15-minute period (undisturbed) and caribou that had been overflown during the previous 15-minute period (disturbed) in Alaska, 1991. Significant ($p < 0.05$) within season differences are noted with an asterisk.

Table 2. Seasonal comparisons (ANOVA) of the effects of low-altitude overflights by military jet aircraft on the daily distance traveled (km) by caribou that had not been overflown during the previous 24-h period (control) and caribou that had been overflown during the previous 24-h period (treatment) in Alaska, 1991.

Season	Group	Mean	SE	*n*	*p*
Late winter	Control	2.7	0.5	29	0.48
	Treatment	1.6	0.3	18	
Post-calving	Control	4.9	1.3	21	0.009
	Treatment	7.4	0.9	21	
Insect	Control	3.6	0.6	33	0.45
	Treatment	1.9	0.5	7	

Our evaluation of the instantaneous reactions of caribou to overflights determined whether specific types of aircraft, SELs, or season influenced the intensity of reactions. We found that instantaneous reactions were mild, seldom involved movement, and, in general, did not suggest that the animals were panicking or exhibiting predator response behaviors (Bergerud 1974). We detected no differences in reactions among seasons, but F-15s, which were the loudest aircraft, caused stronger reactions than did the other types of aircraft.

We also examined whether disruptions of behavior caused by overflights were sufficient to alter the amount of time the animals spent performing various activities. Overflights altered activity budgets during two of the three sampling periods. During late winter, we detected no differences in the activity budgets of caribou that had been recently overflown; however, our results from similar investigations in 1989 showed that, during late winter, caribou that had been overflown recently spent more time feeding and less time lying than did undisturbed caribou (Murphy *et al.* 1991). This difference also was detected during post-calving and the insect season in 1991. A decrease in time spent lying by caribou in response to disturbance has been interpreted to be a subtle, low-intensity response by animals that are aware of a disturbing stimulus and are able to go about most of their normal activities, but that are not comfortable enough to lie down (Murphy and Curatolo 1987).

The results of our analysis of daily movements generally are consistent with the results of our analysis of activity budgets and suggest that the presence of newborn calves in June (and perhaps as late as August) may cause female caribou to respond to overflights more than during other times of the year, when calves are less vulnerable. Preliminary analyses of daily movements and activity of caribou based on data retrieved from *Wildlink* collars support the finding of increased activity associated with increased movement in response to jet overflights during post-calving.

Harrington and Veitch (1991, 1992) evaluated the short-term impacts of military overflights on the behavior, movements, and calving success of woodland caribou (*R. t. caribou).* They found that short-term behavioral impacts were minimal, but concluded that calf survival may have been affected by the frequency of exposure to low-altitude overflights during and immediately after calving. On the other hand, Davis *et al.* (1985) reported that disturbance of the Delta Herd by military aircraft and other factors had not adversely affected productivity.

The results of this study indicate that overall behavioral impacts were mild, but that female caribou reacted to overflights by jet aircraft by lying less and moving more than did unexposed caribou, and that these responses were most prevalent when young calves were present. Females with young calves may be less tolerant of aircraft disturbance than during other times of the year, and the reactions we observed suggest that caribou moved away from disturbed areas. The energetic and demographic consequences of these behavioral responses currently are being evaluated by incorporating our behavioral data into a model developed by the Canadian Wildlife Service and the University of Alaska—Fairbanks.

ACKNOWLEDGMENTS

This project was funded by the USAF and benefited greatly from the support of the Alaska Cooperative Fish and Wildlife Research Unit, University of Alaska—Fairbanks, and the Alaska Department of Fish and Game (ADFG).

Numerous individuals made major contributions to this research program. We wish to thank Major Robert C. Kull, Jr. (USAF), for his input and support; Bill Hauer, Karen Higgs, and Anne Allaye-Chan of the Institute of Arctic Biology, University of Alaska—Fairbanks, for their help with data collection; George Zusi-Cobb of Alaska Biological Research, Inc. (ABR) for logistical support; Major Neil Sharra (USAF) and Sergeant Jay Regan (USAF), who served as our Forward Ground Air Controllers; Patrick Valkenburg (ADFG) and Ken Whitten (ADFG) for leading our animal capture operations; Allison Zusi-Cobb (ABR) for GIS and drafting support; and Robert Day (ABR), Brian Lawhead (ABR), and Betty Anderson (ABR) for critically reviewing this manuscript.

We also are particularly indebted to the pilots from the USAF and the Alaska "bush pilots" who gamely followed our instructions to fly their planes and helicopters in extremely precipitous terrain.

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BEHAVIOURAL PATTERNS OF DOMESTIC ANIMALS AS INDUCED BY DIFFERENT QUALITIES AND QUANTITIES OF AIRCRAFT NOISE

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Abstract: It was investigated whether or not low altitude flying events of seven different types of aircraft will influence productivity, reproduction and behaviour of seven animal species (horse, cattle, pig, poultry, turkey, mink and dog), which were kept under different management conditions as well on pastures as in stables. Here, the ascertained behavioural patterns will be presented.

The aircraft types were
- four fixed-wing aircraft: F 104 g (Starfighter), F 4 f (Phantom), ALPHA Jet and Thunderbolt A 10 (in Germany known as "Warzenschwein = Warthog") and
- three helicopters: Alouette II, Bo 105 and Bell UH 1 D.

The **fixed wing aircraft** normally fly straight ahead at high speed, exempted the A 10, which also is able to fly at lower speed and in quite narrow turns.
The **helicopters,** however, have the ability to fly relatively fast or slow or even to "hover" like immobilized and also to suddenly appear e.g. from behind a forest ("Confined area approach" or "extremely low level flights between obstacles"), so that there is neither an optic nor an acoustic effect for early warning of the animals.

The **four qualities and quantities**, by which sound/noise can be defined, namely frequency distribution (in Hz), sound pressure level (in dB A or linear), steepness or slope of the signal (amount of increase in dB per s) and duration of the sound influence (in s) allow to ascertain the differences between the noise emission of the types of aircraft investigated (Examples see figures 1 a - c and table 1).

Experiences with horses (pregnant mares).

The first group of horses had been kept on a quite large pasture (100 m long and 30 m wide), which was limited by a wooden fence. During the first "blocks" of overflights by fixed-wing aircraft and helicopters the animals showed very intensive escape reactions along the fences or in random movements. This happened mainly when the approaching aircraft could be detected early enough by **acoustic and perhaps optic signals** (the latter especially emitted by the helicopters).
During the later overflights the horses prefered to move towards the exit of the pasture. The fences were never broken or passed. Occasional biting or biting-attempts as well as kicking or kicking-attempts were also observed. No accidents or injuries could be ascertained and the visible excitement did not last for longer than two minutes.

The second group of horses stood individually separated in paddocks (4 m to 4 m each). The helicopter type Bo 105 performed "pendulum" flights, moving towards the animals and pulling back like the swing of a pendulum. During this kind of overflight and also during the first straight ahead overflights of the fixed wing types of aircraft, the animals showed most intensive movements, which of course were locally restricted by the fence. During the hovering of the helicopters, however, as low as only about five meters above the horses, the animals stood mainly motionless. Some of these animals showed strong trembling of their big muscular parts with slight saw-horse-like posture. It decreased after more or less time, partly only after returning to the stable. No longer lasting disturbances could be seen.

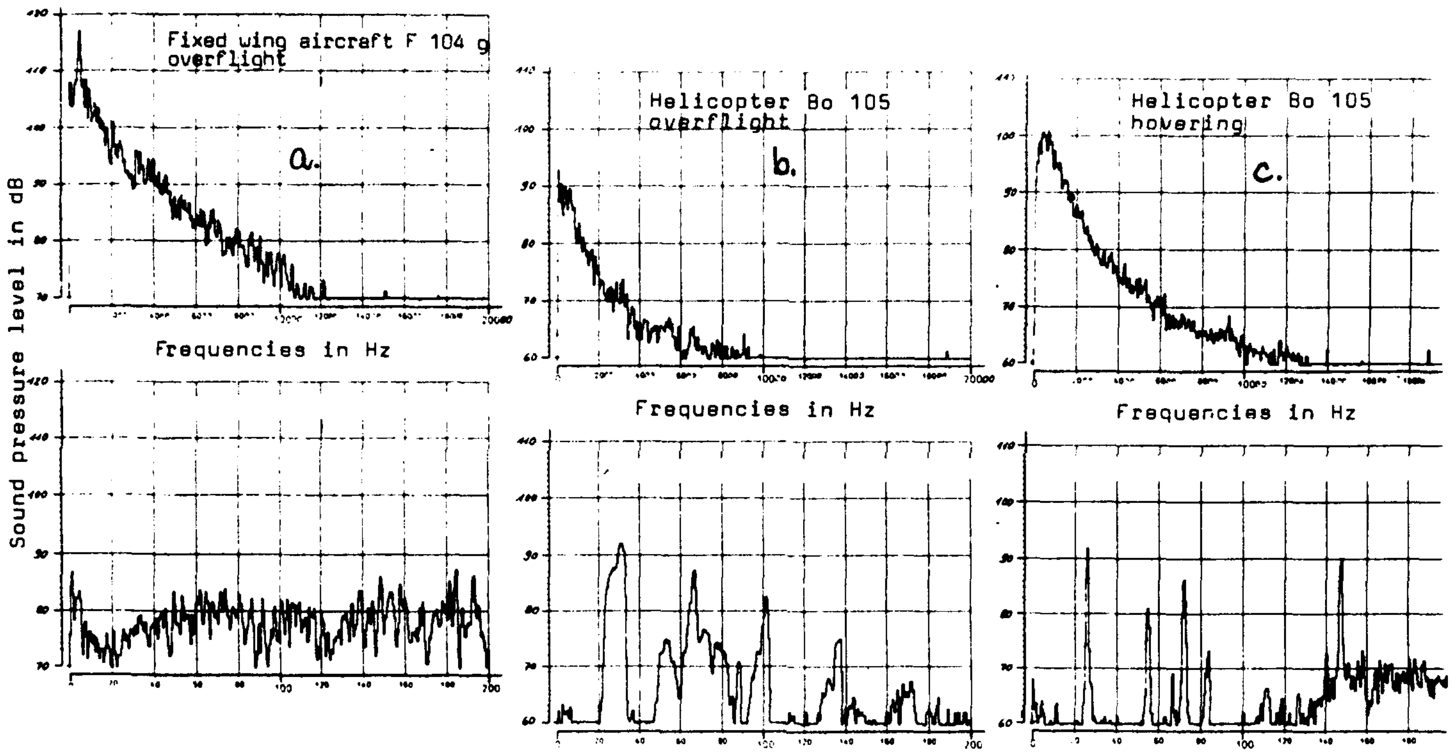


Figure 1 a - c : Example for the frequency distributions of two aircraft (a. F 104 g, overflight; b. Bo 105, overflight; c. Bo 105, hovering).
0 - 20,000 Hz (top), 0 - 200 Hz (bottom)

Table 1 : Example of the records of the proceedings with sound pressure level (L_F and L_{AF}), duration of the sound influences (t_{-10}) and slope of the signal (t_A)

Date	Time	a) Curr. Nr.	Aircr. Type	Speed [kn]	b) Altitude [ft]	c) Altitude [m]	d) Mp 1 L_F [dB]	e) Mp 1 L_{AF} [dB(A)]	f) Mp 1 t_{-10} [s]	g) Mp 1 t_A [s]	d) Mp 2 L_F [dB]	e) Mp 2 L_{AF} [dB(A)]	f) Mp 2 t_{-10} [s]	g) Mp 2 t_A [s]	Time betw. flights
15 5 81	12⁰⁵	19 *	BO105	120	100	KM	101,0	93,5	2,2	6,2	100,5	84,0	4,0	–	–
"		20 *	"	120	100	"	101,0	93,5	2,3	9,2	96,0	80,5	3,8	–	103
"		21 *	"	120	100	"	100,5	94,5	1,8	6,3	97,5	81,5	3,8	–	94
"		22 *	"	100	100	"	100,0	93,5	2,0	6,8	91,5	79,0	3,8	–	100
"		23 *	"	100	100	"	100,0	93,0	2,5	10,2	89,5	79,0	4,0	–	101
"		24 *	"	100	100	"	98,0	90,5	2,8	8,7	90,5	78,0	4,4	–	104
"		25 *	"	80	100	"	98,0	90,0	3,3	8,7	84,5	76,0	5,2	–	112
"		26 *	"	80	100	"	98,5	91,0	3,0	6,3	86,0	77,0	5,0	–	114
"		27 *	"	80	100	"	99,5	92,0	2,5	7,4	87,5	78,0	5,0	–	114
"		28 *	"	60	80	"	99,5	90,0	4,2	12,5	87,5	79,0	9,2	–	119
"		29 *	"	60	80	"	100,0	91,0	4,0	8,4	86,0	77,0	6,5	–	120
"		30 *	"	60	80	"	100,0	90,5	4,2	13,8	88,0	75,5	8,5	–	123
"	12²⁷	31 *	"	Hovering		"	105,0	103,0	39,0	15,2	93,5	85,0	150,0	–	130
19 5 81	11³²	32 *	F 104 G	450	500	80	115,5	115,0	1,5	1,5	108,5	107,5	0,9	1,4	–
"		33 *	"	450	500	KM	110,0	108,5	2,0	1,8	96,5	94,0	3,0	–	118
"		34 *	"	450	500	112	113,0	111,0	1,9	1,3	105,0	104,0	1,3	1,4	90
"		35 *	"	450	500	114	117,5	117,0	1,0	1,1	108,0	107,0	1,0	1,3	115
"		36 *	"	450	500	133	114,5	113,5	1,8	1,2	106,0	105,0	1,3	1,2	107
"		37 *	"	450	500	108	116,0	115,5	1,2	1,1	107,5	107,0	1,2	1,2	101
"		38 *	"	450	500	126	115,0	114,0	1,6	1,2	107,5	106,0	1,2	1,3	105
"		39 *	"	450	500	113	116,0	115,0	1,4	1,0	108,5	107,5	1,0	0,9	89
"		40 *	"	450	500	150	114,5	113,5	1,8	1,9	105,5	104,5	1,3	1,9	116
"		41 *	"	450	500	91	116,5	116,0	1,2	1,2	109,0	108,0	0,9	0,9	92
"		42 *	"	450	500	134	116,0	115,0	0,8	1,2	106,0	105,0	1,2	1,2	114
"	11⁴⁰	43 *	"	450	500	97	117,5	117,0	1,0	1,9	105,0	107,0	0,9	1,0	61

Experiences with cattle (pregnant cows resp. heifers).

The first group of cattle, freely roaming on the pasture, were generally disturbed but without stronger locomotion as a reaction to the direct overflights by fixed-wing aircraft. Contrary to these observations the cattle showed plainly visible movements by direct overflights of helicopters. However no panic escape movements or uncontrolled stampede-like behaviour had been observed at all.

For **the second group of cattle**, one year later and on the same pasture, the central longitudinal axis of the area was equippedwith a **double row of staggered pales** with passages not much wider than animal's body. When passing this double row, even during the overflights, the cows avoided the obstacles showing almost elegant movements without touching the pales.
This group of ten animals was also exposed to different types of overflight including the "confined area approach in extremely low level". Especially during the overflights by the helicopter types Alouette II and Bo 105 most of the cows were rather strongly impressed, but there were noticeable individual differences between the animals. They also liked to jostle into a corner of the pasture and continued moving as a unified group towards the (closed) exit. Once, the first animals on the periphery were pushed against the intentionally weaker fence by the following ones, so that two of them were climbing through the horizontal crossbeams of the fence without exceptional force. When the helicopter left the pasture, the group dispersed again and the animals showed orientation behaviour and tried to hold optic contact with the cattleman outside the fence who usually looked after them.

The third group of cattle, finally, was mostly tied in an stable, with the head in front of the closed wall and in direction of the approaching aircraft, the opposite (tail) side being open. Here, the fixed animals were strongly excited by the low level overflights of the fixed-wing aircraft. They tried to get body contact with their neighbours and to gain a position where they could see the leaving aircraft behind them. With increasing number of overflights the reactions became weaker, but tension, body contact and kicking with hind legs could be further observed.
Especially the hovering helicopters impressed the fixed cows very much, both by the noise and by the optic and tactile influences of whirled up straw and dust. The most striking features were in that case a stiff body position and superficial breathing (panting). Even two and a half hours after the overflights three of the twenty animals had not yet calmed down.

Experiences with pigs (pregnant sows).

The sows were overflown either as a group of ten animals in a solid stable with access during daytime to a special pasture, 7 m to 30 m, or as a group of twelve sows, kept in single boxes in a light wooden stable nearby.
The only sign of irritation was some intensified wagging of their tails. Even when **the helicopters tried to chase** them repeatedly from the one end of the pasture to the other and returned by hovering at an altitude of not more than five meters above the animals - with all the acoustic, optic, tactile and probably olfactoric (by the waste gas) stimuli - the sows went mostly only slowly and step by step with horizontally flapping earlobs (by the "downwash" wind). Very short trotting phases were always stopped after a few steps. After a couple of days with daily overflights, one of the sows on the pasture remained comfortable streched out on the soil with closed eyes despite the strongest influences of a helicopter hovering at low altitude. Only from time to time the sow opened one eye for control of the surroundings. After the end of the overflights she stood up easily and moved slowly towards the other sows of the group.

Experiences with poultry (chicken, broilers and laying hens).

These animals were housed in two light shelters beside of the pastures used for the horses, cattle and pigs under observation.
The five to seven days old animals (**chicken**) lived inside a circle-shaped wall which provided the necessary warmth and limited the possibility of locomotion. During the first three days of overflights by the fixed-wing aircraft type F 4 f Phantom they showed behavioural patterns which never

happened during other times of the experiment. Accordingly, nearly all the chickens performed a centrifugal movement towards the circle-shaped wall, where they climbed on top of each other piling up at the walls. Between the overflights of these days this chicken heap decreased and increased again during the next overflight. This phenomenon diminished in the course of the three overflight days. There were no losses in that period. No orientation behaviour was observed.
Straight ahead overflights by helicopters of the type Bo 105 induced only orientation behaviour with standing up and rising of the head, whereas hovering of the same aircraft type was accompanied by centrifugal movement and building up a circle-shaped heap on the border for several minutes. Here, too, the procedure lessened later but, it was replaced by orientation behaviour.

The **elder animals (broilers), three to five weeks old**, kept without a circle shaped wall were overflown by the helicopter type Bo 105. They did not show centrifugal movement, but only orientation behaviour and undirected locomotions.

The **laying hens**, finally, showed only orientation behaviour during the first two days of overflights by the fixed-wing aircraft type F 4 f Phantom with decreasing activity on the third day. On that day some of the hens even slept peacefully. The same observations were made during the straight ahead oberflights by helicopter type Bo 105.
Under hovering overflights, however, more than the half of the hens started some directed locomotion towards the dividing wire-mesh of the other part of the shelter. This locomotion was performed slowly and not at all in panic. The orientation behaviour was more distinct in overflights of the Bo 105 aircraft, compared with F 4 f Phantom aircraft.
These behaviour patterns show that there are three important factors which influence the events: Type of overflight, age of the poultry and adaptation or sensibilisation of the animals.

Experiences with turkey (Chicken, joung cockerels, joung hens, elder cocks, elder hens)

The **chicken**, one day old and older, formed larger groups of animals, laying motionless close together on the straw-covered floor under the overflights and hovering of helicopter type Bo 105, without trying to observe the source of the noise.
Later on, when 21 to 23 days old, they showed a decreasing activity to form groups under overflights and hovering of the Alouette II helicopter type.

During the first hoverings of helicopter types Bo 105 and Alouette II one chicken of each group was running across the circle to another group. This situation was not accompanied by general agitation or panic with the risk of losses.
Finally, at the age of 33 to 35 days and under the influence of straight ahead overflights of fixed-wing aircraft F 4 f Phantom they reacted only by orientation behaviour with decreasing activity.

In the group of the **young cockerels** the resting behaviour increased generally in the course of the overflights. Only one cockerel was running on day eight of the overflight series (F 4 f Phantom) across the stable, beating its wings and becoming ruffled.

The behaviour of the **young hens** was very similar to this of the young cockerels.

The **elder cocks** showed a strong orientation behaviour during all the overflight events. Until about 20 % of the animals ruffled their feathers, which can be explained as an increased activity. Only during the first hovering of the Bo 105 helicopter type a group of animals was formed, from which three cocks flied centrifugally. It is unknown whether or not the acoustic stimulus or whether or not the tactile stimulus of the downwash wind, coming through the cracks of the walls, was triggering the escape behaviour.

The **elder hens** showed slight decreasing of their strong orientation behaviour and of the slow formation of groups in the course of the overflights. During the hovering of the Bo 105 on the first day of overflights and during an Alouette II hovering in the middle of the overflights days one hen of each group had run across the area, beating its wings.

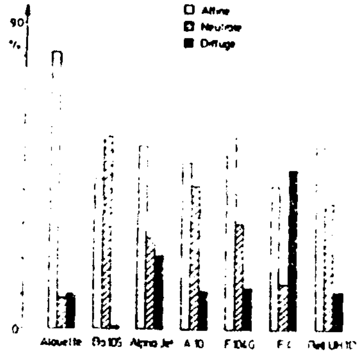
Experiences with minks (pregnant females)

Here, the overflight events, used as stimuli, could be put in a medium grade category. In the beginning of the overflights arose from conflict behaviour a short time escape behaviour, which changed quite fast to orientation behaviour. Some of the females, with and without whelps, showed in some cases also conflict behaviour, which was not limited to overflight situations, but happened also in temporal connection with other stimuli and had no negative influence on the rearing behaviour. Generally, the reactions of the female minks to overflight stimuli depended on the kind of event (acoustic stimuli without any optic component or an event or a combination of acoustic and optic stimuli). The first one, mostly produced by straight ahead overflights both by fixed wing aircraft and helicopters, initiated lesser reactions, the second one, made mainly by hovering helicopters, was also followed by quite short but stronger reactions. There was no influence of helicopter type, but of genetic difference in the sensitivity of the two mink breeds, the "Saphir" females possessing a higher sensitivity compared with "Black cross" females.

Experiences with dogs (adult larger watchdogs).

The behavioural reactions of these animals had been described by the TEMBROCK system, with a subdivision into "affine status" and "diffuge status" each of different grades, besides of a "neutral status", "inhibition of the movement" and "conflict behaviour".
Even though the helicopter type Bo 105 was louder than the helicopter type Alouette II, the reactions to Bo 105 by "neutral" behaviour were considerably less. This could be considered as an effect of different frequency distribution with a peak between 10 000 and 12 000 Hz up to 18 000 Hz compared with Alouette II. The reactions to the helicopter type Bell UH 1 D were not so strong although the well-known typical "carpet-beater" noise was noticeable. The strongest reactions were produced by the fixed-wing aircraft type F 4 f (Phantom) with a high percentage of diffuge behavioural patterns. There were different percentages of affine, neutral and diffuge reactions in dependance on the aircraft types used (Figure 2).

Figure 2:



Conclusions:

About the seven species of animals under observation, the following conclusions with regard to behavioural patterns under low altitude overfly events can be drawn:

- **There are species-specific, breed-specific and individual differences in type and intensity of behavioural reactions.**
- **There are differences in the influences of overflights, based on the quality and quantity of sound emission by the aircraft type and on the procedure of over-flying (straight ahead or hovering).**
- **There are indications for some adaptation of the animals to the immitted noise.**
- **There are no indications for a longer sensitization of the animals to the immitted noise.**

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OVERVIEW OF USAF STUDIES ON THE EFFECTS OF AIRCRAFT OVERFLIGHT NOISE ON WILD AND DOMESTIC ANIMALS

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ABSTRACT

The United States' National Environmental Policy Act of 1969 requires that all Federal agencies assess the impact of proposed operations on the environment. For this reason, the US Air Force's Noise and Sonic Boom Impact Technology (NSBIT) program office has planned, developed and orchestrated a program to assess the impact of aircraft noise on animals, both wild and domestic. The Air Force's research program examined the current state-of-knowledge, determined technology gaps in our current understanding, assessed the greatest needs for additional research, and executed the research plan. This presentation will provide a brief overview of the research accomplished to date for both domestic animals and wildlife. For domestic animals, NSBIT contracted studies to examine the effects of aircraft overflight noise on domestic turkeys, pregnant mares, and on milk production in dairy cattle. As a result of the these studies, as well as a meta-analysis of all previous research, a model has been developed to predict the effects of aircraft noise on domestic animals. For wildlife, several studies will be presented concerning bighorn sheep, caribou, kit fox, and birds of prey. Dose-response models for various types of wildlife are also being developed. In addition to the results of these studies, NSBIT's future research plans will be presented.

INTRODUCTION

The National Environmental Policy Act (NEPA) of 1969 and Air Force Regulation 19-2 requires that the US Air Force (USAF) assess the impact of proposed flight operations on the environment. Within the local environs of an airbase, like many community airports, aircraft overflight noise

may increase the prevalence of annoyance when average noise levels increase. Aircraft traffic patterns and normal approaches may also overfly ranches and farms where domestic animals are raised for meat or other commodities. Caretakers of these facilities have claimed damage to their domestic animals due to aircraft overflights and the associated noise. Rarely has there been concern for wildlife within the airbase vicinity.

The USAF also conducts training flights along designated Military Training Routes (MTR) and within Military Operating Areas (MOA) where aircraft travel at very low altitudes and high speeds. These flight routes are in rural areas, but the land underneath may be publicly or privately owned. These lands may contain domestic livestock, but much of the area contain wildlife that could be sensitive to aircraft overflight noise. For these reasons, its incumbent upon the USAF to understand the potential effects of aircraft noise on animals, both domestic and wild.

In 1984 the USAF formed an advanced development program office to address issues regarding the effects of aircraft noise on humans, animals, and structures. This office, the Noise and Sonic Boom Impact Technology (NSBIT) program office, develops contracted efforts to study the effects of noise on wild and domestic animals and thus fulfill the USAF obligation to be good stewards of the lands it overflies. Since its inception, the NSBIT program has sponsored a variety of studies to examine the effects of aircraft noise on animals. The purpose of this paper is to briefly describe some of these projects as well as outline future projects envisioned.

AIRCRAFT NOISE EFFECTS ON WILDLIFE

In 1988 NSBIT sponsored a research needs workshop. The purpose of the workshop was to "identify and prioritize research needs on the effects of aircraft noise and sonic booms on fish and wildlife" (Asherin and Gladwin 1988). Attendees to the workshop included various wildlife experts including U.S. Fish and Wildlife Service, many private research companies, U.S. Bureau of Land Management, U.S. Forest Service, National Wildlife Refuge managers, State departments game and fish, environmental consulting firms, Department of Defense environmental planners, and university professors. Their task was to identify technological gaps in the literature, prioritize research needs, and make recommendations for research on the effects of noise on wildlife. The following five groups of animals were identified as having the highest priority:

1) bighorn sheep
2) caribou
3) geese
4) wintering waterfowl

5) denning bears

In 1989 NSBIT set out to study the effects of aircraft overflights on bighorn sheep and caribou. NSBIT established a basic methodology for both of these studies. Each study would undertake a controlled laboratory approach where simulated aircraft overflight noise was used to investigate the effects of behavioral and physiological effects. A less controlled field study would be performed using actual aircraft overflights by high performance fighter aircraft.

Aircraft noise effects on Bighorn Sheep: The University of Arizona, in conjunction with the U.S. Fish and Wildlife Cooperative Unit at the University, performed the study on the effects of aircraft noise on Desert Bighorn Sheep and Desert Mule Deer. Within the confines of small pens, researchers measured heart rate, body temperature, and behavior in relation to simulated aircraft overflights. Noise levels experienced by these animals ranged from 92 to 112 dBA. All animals habituated to the sounds of low altitude overflights quickly and although heart rates during these noise events increased, they returned to resting rates in less than two minutes (Krausman et. al. 1992).

For the bighorn sheep field study, the USFWS, Nevada State Fish and Game Department, the U.S. Bureau of Land Management and the University of Arizona, in cooperation with the USAF, built a 1.5 sq. mi. fenced area within the Desert National Wildlife Refuge. Twelve Desert Bighorn Sheep were placed within the enclosure for one year without scheduled aircraft overflights. Researchers documented habitat and vegetation usage by the sheep during the 12 months prior to aircraft overflights. During the second year F-16 aircraft flew individual sorties over the enclosure while biologists on the ground attempted to monitor heart rates and behaviors of the animals. Similar results to the controlled laboratory studies were found. The conclusion was that aircraft overflight noise did not appear to affect the population of Desert Bighorn Sheep. In fact, each of the six ewes in the study had lambs each Spring of the study.

Aircraft noise effects on caribou: The University of Alaska, in conjunction with the U.S. Fish and Wildlife Cooperative Unit and Alaska Biological Research, performed the study on the effects of aircraft overflight noise on caribou. The Institute for Arctic Biology at the University of Alaska and other researchers had previously documented the energetics of basic caribou behaviors. This information was valuable for the USAF study, since the main concern for the effects of aircraft overflights on caribou was whether caribou startled by aircraft could cause them to expend more energy than they could afford and therefore affect the population dynamics.

The caribou study was structured similar to the bighorn sheep study,

in that researchers performed controlled laboratory experiments and a field study with actual aircraft overflights. The laboratory study focused on the increase in heart rate due to simulated aircraft noise. Heart rate increases were then translated to increased energy output. For the field study, a special noise monitor was developed to record the aircraft overflight noise. This device was specially designed to attach to the collar of a caribou; five animals wore these devices. Additional animals wore collars with activity monitors attached. Collared animals were released back into the wild and observed during F-15, F-16 and A-10 overflights. One week of aircraft overflights occurred during each of three seasons-- early spring, late spring and late summer. The final report for this study will be completed this summer.

NSBIT's goal for these research projects and others in the future is to develop a model to predict the effects of aircraft overflight noise on various types of animals. In order for a model of this type to be developed, a dose-response relationship must be established. These research projects on bighorn sheep and caribou combined with other research projects on ungulates may one day help to provide sufficient information to develop a predictive model for grazing animals.

Aircraft noise effects on raptors: In an attempt to demonstrate how a dose-response model could be developed, Awbrey and Bowles (1990a) built a preliminary model for raptors based on a synthesis of the literature (Bowles, Awbrey and Kull 1990). Their "straw man" model is a very conservative attempt to predict a worst case approximation of the relation between aircraft noise exposure and reproductive success. Even though this model is hypothetical, it demonstrates a first attempt at predicting aircraft overflight effects. Since the literature suggest a weak link may exist between flight responses and effect, the prediction is based on the proportion of flight responses induced. They also presume that long periods spent off the nest can cause effects. In order to account for the likelyhood of habituation, the proportion of flight responses decline progressively with repeated aircraft overflights. Furthermore, the likelihood of response is associated with aircraft approach distance and sound level. Future studies are planned to validate this model.

Aircraft noise effects on predator-prey relationship: In the thirtysome years that researchers have studied the effects of aircraft noise on wildlife, most studies were performed on diurnal animals. No attempt was ever made to study the effects of aircraft overflight noise on nocturnal animals. Typically nocturnal animals have acute hearing for one of two reasons-- either to hear prey or detect potential predators. For this reason, NSBIT was interested in studying the effects of a predator-prey relationship where hearing was essential for both animals. In 1991 a study began to investigate the effects of aircraft overflight noise on the Desert Kit Fox and its small mammal prey on the Barry M. Goldwater Gunnery Range (Bowles et. al.

1992). The study will continue for one more breeding season, but preliminary results will be presented in another presentation.

FUTURE RESEARCH PLANS ON WILDLIFE

Unfortunately, there are many more species of concern regarding the effects of aircraft noise than project resources can satisfy. However, the Air Force has developed preliminary plans to study the effects of aircraft noise on various wildlife species. The following list is not in any type of priority, since requirements of the operational commands may affect when some studies take place.

Improved version of the Animal Noise Monitor: Upon reviewing all of the research performed to assess the impact of noise on animals, the most common error in much of the research is lack of detail of the description of the stimuli. Unfortunately, only a small minority of researchers attempted to characterize the noise used to stimulate effects. Another problem with past research on this topic and one that is inherent to field studies on wild animals, is the question of level of exposure. In the past it was nearly impossible to record noise levels the animals were exposed. For these reasons the NSBIT program office was interested in developing an Animal Noise Monitor (ANM). The ANM was originally developed for the field research on caribou. ANM version 1 was designed to operate unattended for up to six months, be attached to a collar of a caribou, and collect acoustical data. Furthermore, the ANM was designed to operate under extreme environmental conditions and record simple activity movements immediately following a noise event. The initial development of the ANM was successful, yet several changes were desired after testing the system. The next ANM version will contain improved data storage capacity, small in size, and more reliable.

Effects of aircraft noise and sonic booms on denning bears. This study would more than likely be focused in Alaska where bears are very prevalent. Preliminary work will be accomplished to determine the noise levels inside bear dens during normal aircraft operations. The next step will be to estimate the percentage of the population that may be affected by USAF operations. If a study is justified, research will be performed to determine if the aircraft disturbance is sufficient to disturb hibernating bears and the effect this disturbance may have on population dynamics.

Effects of aircraft noise on moose. Most recently, there have been claims that Air Force operations have caused a reduction in the number of moose obtained during hunting season. This study would try to determine if aircraft overflights affect the distribution of moose from preferred habitat. Since these animals do not regularly occur together in large numbers, special devices are being designed to record aircraft noise parameters, animal movements and location using a global positioning system.

Effects of aircraft noise on waterfowl. Several preliminary studies have indicated that further work should be done on the effects of aircraft disturbance on geese in Alaska. Most of the previous studies were performed with helicopters or small fixed-wing aircraft. Waterfowl readily respond to aerial predators and it seems reasonable that geese and ducks would react to these types of aircraft when flown overhead. However, it is not clear whether high-speed jet aircraft wouid initiate a similar reaction. For this reason, more research is required to examine the effects of jet aircraft overflights on waterfowl behaviors.

AIRCRAFT NOISE EFFECTS ON DOMESTIC ANIMALS

In the advent of high speed flight and through the last thirty years concerns have been raised regarding the effects of aircraft overflights on domestic animals. Claims have been made against the Air Force for serious effects, including breaking chicken eggs and reducing hatchability; lowering the productivity of laying hens; stampeding cattle; abortions of pregnant animals; cannibalization of early young; and reduction in the production of milk from dairy cattle. The Air Force conducted three studies since 1989 in an attempt to substantiate claims that these effects occurred. All three studies used simulated aircraft overflights as a stimulus for potential behavioral and physiological responses.

Effects of aircraft noise on behavior, milk production and composition of lactating dairy cows. In 1989, H. H. Head at the University of Florida studied the effects of aircraft noise on dairy cows. In addition to behavior and milk production, Head examined the release of prolactin and cortisol from lactating dairy cows (Head 1992). Dairy cows showed no signs of behavioral reaction, nor was there a change in milk yield, milk component percentages or residual milk resulting from the aircraft noise disturbances.

Effects of aircraft noise on pregnant mares. In another study at the University of Florida, LeBlanc et.al. (1991) examined the effects of aircraft noise on pregnancy outcome, behavior, rate of habituation, cardiac function, serum cortisol and progestogen concentrations of pregnant mares. All treatment mares (8) delivered live, normal foals without assistance. There were significant differences in the anxieties and movements of the treated mares compared to controls and heart rates increased during noise events. However, no injuries occurred and no ectopic arrthymias were observed. LeBlanc observed some adaptation to the noise events, both behaviorally and physiologically.

Effects of aircraft noise on domestic turkeys. This study, performed at the University of California at Davis, sought to quantify the relation between sound characteristics of overflights and turkey responses, to determine how

rapidly turkeys habituate, and to measure effects of worst case exposure on weight-gain, mortality and carcass quality (Bradley, Book, and Bowles 1990). Bradley found that turkeys habituate very rapidly to aircraft overflights. She also stated that turkeys exposed to chronic worst-case aircraft overflight noise grew at the same rate versus controls, but had some behavioral differences and were somewhat more difficult to handle. Bradley reported that Sound Exposure Level (SEL) was the most useful predictor of responses.

In an attempt to form a model to predict the effects of proposed aircraft overflights near farms and ranches, a meta-analysis was accomplished (Bowles, Yochem and Awbrey, 1990). In addition, the USAF claims files were examined to determine the prevalence of occurrence of animal damage due to aircraft overflights. Several assumptions were made in order to form this "dose-response" model. The assumptions were 1) that naive animals respond most strongly, and will experience the greatest effects after single overflight incidents, 2) that experienced animals will not panic, but they will be susceptible to effects due to cumulative exposure, 3) that normal rates of trauma induced by panic are very poorly documented, and 4) that possible subtle effects on weight gain, milk yield, productivity, and fertility are either non-existent or difficult to observe. Bowles et.al. (1990) formed three major groups for the model: large stock, poultry, and fur bearers and swine. The fur bearers part of the model was not implemented since there was a lack of data to make predictions on the losses due to aircraft overflight noise. However, for the other two groups, Bowles et.al. predict separately the possibility of traumatic loss due to panic and the possibility of losses in production (eggs, meat, young, etc.). Future research will involve testing the model to determine its validity.

FUTURE AIRCRAFT NOISE RESEARCH ON DOMESTIC ANIMALS

Aubrey and B[illegible] developed a research plan recommending [illegible] Air Force pursue [illegible] where technological gaps exist. The following studies have been planned for the future.

Clinical surveys. A series of clinical surveys will be accomplished to determine the incidence of serious effects on domestic animals due to startling stimuli, including low-altitude aircraft.

Effects of aircraft noise on stockyard cattle. This study will set out to determine the probability of aircraft overflight disturbance on large livestock contained in stockyards.

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Noise and Man '93 - Nice FR

Summary of Team 7

Prior to the Noise and Man 1988 meeting in Stockholm, very little progress had been made with respect to research documenting the effects of noise on animals. It is true that many studies had been done, but the majority of researchers had not or could not document the noise exposures nor provide definitive answers to our questions of potential impact on noise on animals. Most studies in years past dealt with describing gross escape reactions and related behaviors, but these studies did not get us any closer to answering the question "So what?". Researchers in many cases did not address confounding variables such as weather-related phenomena, predation pressures, prey abundance, or the impact of the presence of the researchers themselves within the study area. However, since Dr. Pederson's summary report to ICBEN in 1988, considerable progress has been made. To a great extent, our progress is due to rapid advances in technology. For instance, we found it is possible to accurately measure noise exposures to individual experimental animals in the wild by the development of portable dosimetry devices, small enough to be worn on the collars of caribou or other large mammals. Improved telemetry equipment has allowed us to monitor heart rate, body temperature, animal activities, and geographical location over great distances and with greater precision than ever before. We have begun to develop standard methodologies and practices for studying wildlife in their natural habitats, again attributable to high technology. In 1988 several large, and very costly studies began in order to advance our state-of-knowledge of the effects of aircraft overflight noise on wildlife and were reported on this week.

Thirteen papers on a diversity of topics were presented during the Team 7 sessions. Six of the thirteen papers were related to the effects of military aircraft noise on animals. This is probably attributed to the fact that military funding has been provided in

order to satisfy environmental impact assessments required by law in the reporting countries. The types of noise sources reported on this week varied considerably too, from aircraft noise and steady state noise to blase noise and infra-sound. Large terrestrial mammals was the main concern of most of the reports. Where researchers were able to perform tightly controlled studies, evidence of noise effects was nil to low on individual animals and as yet evidence of significant effects of noise on wildlife populations is low to minimal. The exception was a report documenting non-auditory effects of complex weapon blast pressure waves on pigs in small enclosures. Though we have made considerable progress within the last five years, compared to the other topics of my colleagues regarding the effects on noise on humans, we have a long way to go before we can be definitive. We do not have definitive theoretical models of dose-response, let alone the data for these models. In our defense, however, we must be concerned with literally thousands of species, not just one, Homo sapiens; not just urban and rural environments, but habitats as diverse as the hot sands of the Mohave Desert to the bitter cold arctic tundra to the humid jungles of the tropics. The homes of our noise-exposed participants do not have their windows opened or closed and we cannot insulate for noise environments. Our subjects live outside, in caves and cavities, in trees or underwater. And we can't present our subjects with questionnaires inquiring as to their sensitivity or their relative annoyance. We can't even ask participants how they feel about "this noise" or "that noise". Researchers represented from Team 7 must be out in the field with their subjects for long hours, fighting blood sucking mosquitoes and enduring enclimate weather. But I'm not trying to make excuses for why we are not as far along as other teams may be, just stating facts of the severe conditions in which many biologists must work and I hope that others may be able to appreciate our task.

Well, what will the next five years bring us. I believe it is extremely important for Team 7 to remain as an active team within ICBEN. We all know that there is an ever-increasing focus on the

environment and how we impact it. For this reason, it is important that Team 7 continue to improve our communication amongst our members as well as increase our small group by promoting participation within other countries. It is imperative that we encourage biologists working in this area, but who are unaware of our acoustics conferences, to join our ranks. We are especially interested to include marine mammalogists, since we recognize the desperate need for research on the effects on noise on whales and other large marine mammals. We currently have a great need for standards and criteria by which environmental planners can assess the impact of proposed actions, however our current state-of-knowledge does not allow us to make such conclusions and therefore we are unable to fulfill this requirement at this time.

With these observations in mind, I conclude with the following five goals for the next five years: I am challenging members of Team 7 1) to establish appropriate metrics for use in describing exposures of noise to animals, 2) to determine the long term effects of noise on populations of wildlife; 3) to establish dose-response models to predict effects of noise; 4) to begin to seriously study the role of habituation in populations; and 5) to begin to establish noise exposure criteria and standards.

I want to take the time now to thank all the members of Team 7 for their participation and especially to my Co-Chair, Lex Brown. I am looking forward to these next five years and hope that I will be able to report to you extensive progress towards these objectives.

ACOUSTIC INATTENTIVENESS AS AN INDICATOR OF FATIGUE IN PHYSICALLY LOADED ALSATIAN WATCHDOGS

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Abstract: The acoustic attentiveness of watchdogs with regard to different guarding relevant noises decreased with prolonged patrol walks, higher air temperature/air humidity conditions and lower individual robustness of the animals. It would be imprudent to overload the animals in a thoughtless way not only for reasons of animal welfare and well-being but also because of the decreasing guarding effect.

Usually, watchdogs are kept to defend an area or to support the attentiveness of the watchmen by specially suited senses. Of these senses, the acoustic and olfactoric ones are of particular interest, whereas the optical sense is mostly of minor importance. Maintenance of a couple of well educated and specially trained dogs is quite expensive. So, the guarding companies and military services sometimes tend to decrease expenses by reduction in the number of dogs. The (wrong) assumption is: The same work for less money, meaning that fewer dogs should work more hours per day.
In that context the behaviour of six Alsatian watchdogs was investigated. Of particular interest was

- primarily, whether or not increased physical loadings exceeded the physical and/or mental abilities of the animals and hereby violated the animal welfare legislation and
- secondly, whether or not these animals in the more loaded status developed the same attentiveness with respect to environmental stimuli as they did under lower loading conditions.

The physiologically important criteria such as **heart frequency, respiration frequency and traction power**[1] were recorded, but they are not subject of this paper. The **attentiveness** of the dogs, here particularly of interest, was checked after their more or less tiring work in a treadmill (running rubber tape, fig.1) by means of behavioural audiometry in a special type of kennel (Fig.2) *with regard to guarding-relevant noises of different qualities with higher and lower intensity.*

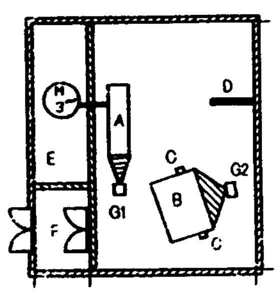


Figure 1:
Air-conditioned test room with equipment
A Treadmill (running rubber tape)
B Audiometry kennel
C Loudspeakers (right and left)
D Wooden screen (for the malingerer)
E Machine room (with electric drive M 3)
F Anteroom
G Video cameras

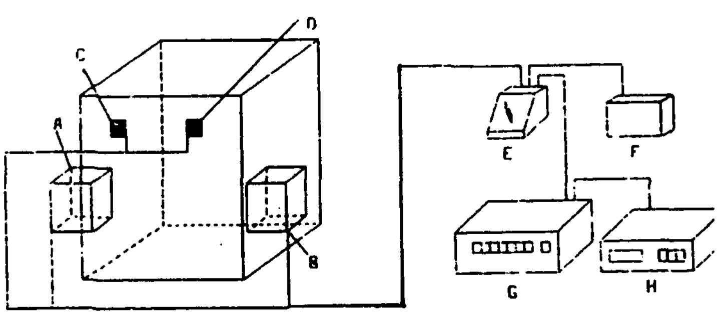


Figure 2:
Equipment of audiometry kennel in testroom (left) and in observation room (right):
A + B Loudspeakers (right and left),
C + D Electric bulbs (right and left),
E Switch (right/left), F Car battery,
G Amplifier Denon PMA 1520,
H DAT recorder Sony DTC 1000 ES

[1] Traction of the dog on the leash when marching on a treadmill

The **variable external testing conditions** consisted of

- duration of the working periods on the treadmill (0.5 - 2.0 hours),
- different grades of ascent of the treadmill (0%, 5 %, 10 %),
- different speeds of the treadmill (2.5 - 5.0 km per hour),
- different duration of breaks (1 - 2 hours),
- different climatic conditions (+20°C, 80% rel. humidity and -10°C, 60-75% rel. humidity).

The **activities producing guarding relevant noise** as they occur in practice, and their <u>sound pressure levels applied here</u> and expressed as "loud" and "soft" (in dB, linear), are shown in <u>table 1:</u>

- Wirecutting by a pair of pincers	"loud" 68,4	"soft" 48,4
- Snapping of branches by treading	72,0	51,9
- Smashing of a glass pane by hammer	68,0	48,3
- Chafing of a pine branch on jeans trousers	49,5	32,0
- High frequency breathing of man	47,3	32,5

The <u>figures 3 - 5</u> allow to recognize on the example of three of the five applied noise types how different the **original acoustic emissions** had been (sound pressure, here from technical reasons indicated as voltage differences, vs. time course (in ms) and sound pressure level (in dB linear) vs. frequency analysis (in Hz):

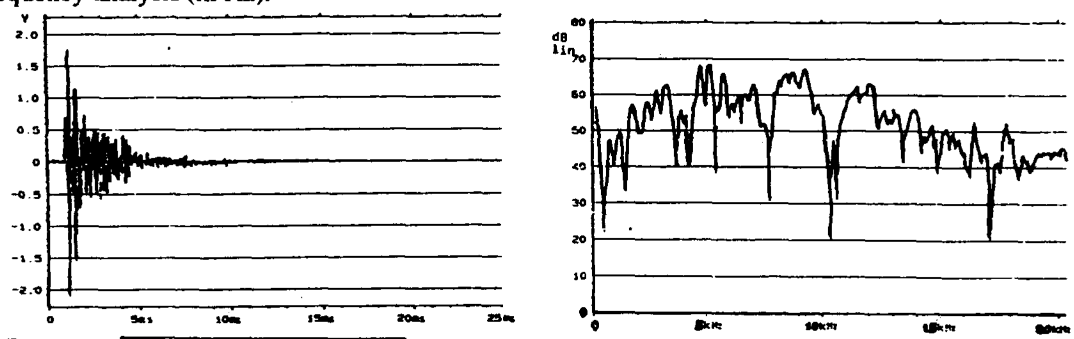


Fig.3 Wire cutting by a pair of pincers

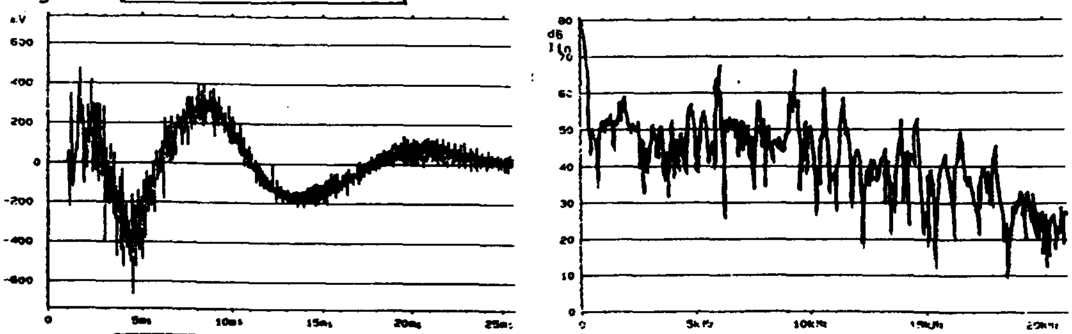


Fig.4 Smashing of a pane of glass by hammer

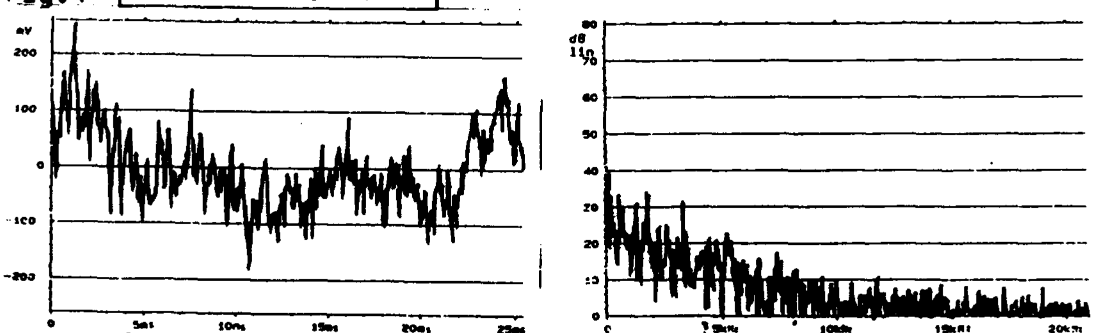


Fig.5 High frequency breathing of man

Immediately after the motoric loading of the dogs in the treadmill, the animals were brought into the **audiometry kennel**, where their had to undergo the influences of the noises, described in table 1, emitted either by the right or by the left loudspeaker. For better video evaluation each of the loudspeakers was connected with a small lamp on its side (electric bulb, facing outwards), so that the applied sound was accompanied by a lighting up of the respective lamp. Consequently, the evaluating assistent saw simultaneously an optical sign, whenever one of the two loudspeakers in the kennel emitted the noise.

The **motivation of the animals** to indicate the acoustic signal was attained by allowing them to bite in the protecting sleeve of a simulating perpetrator instead of the usual offering of feed.

The **behavioural responses** of the dogs were valued as positive ones if a reaction happened in direction of the source of the noise or somewhere else, with a clear temporal connection with the occurence of the noise.

Such a visible reaction could be made by the animals by means of

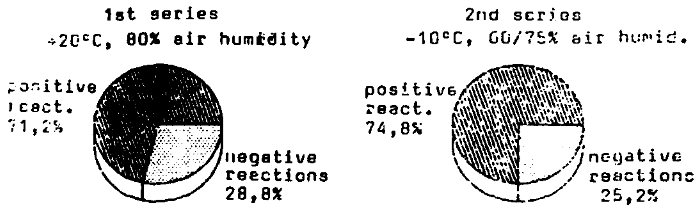
- **the ears**: (here: the auricles)	Judgement 1 = Complete movement of the auricles with the opening exactly in direction of the source of the noise, Judgement 2 = Incomplete movement of the auricles, facing their openings not in direction of the source of the noise.
- **the eyes**:	Judgement 1 = Looking exactly in direction of the source of the noise, Judgement 2 = Every other eye movement.
- **the head**:	Judgement 1 = Complete turning of the head, facing the longitudinal axis directly towards the source of the noise, Judgement 2 = Incomplete turning of the head and stopping of the movement before the facing of the longitudinal axis towards the source of the noise was attained.
- **the trunk**:	Judgement 1 = Complete turning of the trunk with the longitudinal axis in direction of the source of the noise, Judgement 2 = Incomplete turning of the trunk.

Results of the behavioural tests:

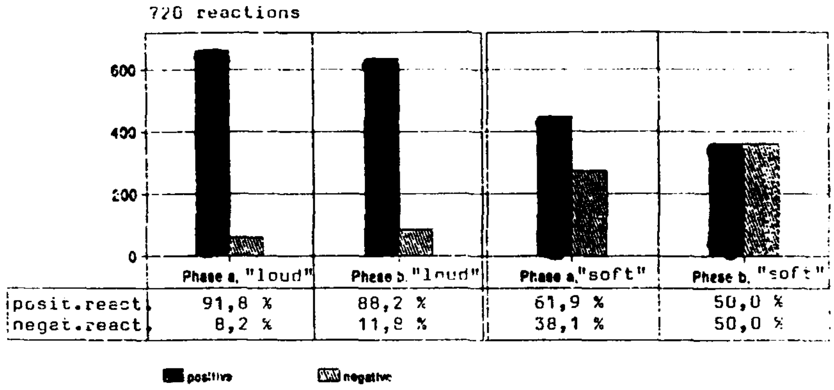
2880 audiometry tests were made altogether during these series of experiments. 73,0 % of them showed a positive behavioural reaction, 27 % were negative.

The influences of the air temperature/air humidity conditions caused, that the animals in the cooler environment (simulated wintertime, -10°C, 60-75% rel. humidity) showed with 74,8 % significantly more positive reactions than under warmer and more humid conditions (simulated summertime, +20°C, 80% rel. humidity) with 71,2 % ($p < 0,05$), (Figure 6). It could not be decided, whether or not the animals under warmer environmental conditions did hear the test noises but were not willing to react or whether or not they had difficulties to hear them because of their own relatively loud respiration (panting) noises.

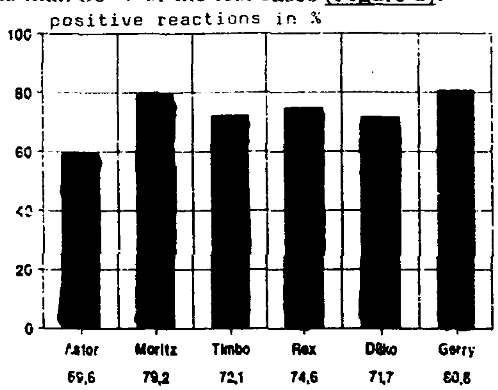
Figure 6: Results of behavioural audiometry under different air temperature/air humidity conditions.



The amount of positive reactions on the "loud" and the "low" noise stimuli **after two joint loading phases** (A, first of two, and B, second of two) was less different for the "louder" signals than for the "lower" ones ($p < 0.01$) (Figure 7).



Concerning the **individual answers** of the dogs all over the different loading variables mentioned above, it could be detected, that two of the six individuals (called GERRY and MORITZ) reacted positively in about 80 %, one of them (ASTOR) in about 60 % and the remaining three (TIMBO, REX and DÜKO) in 70 to less than 80 % of the test cases (Figure 8):



Conclusions:

- **In the course of several coupled phases of motoric loadings, the acoustic attentiveness of the animals decreases**, especially with regard to low intensity noise stimuli.

- **The type of the noise stimuli affects the attentiveness.** Therefore, noise with an impulse-like character will be announced more frequently by the dogs. The education of the animals should include the use of noise qualities with different pressure/time courses.

- **Higher air temperature combined with higher air humidity decreases the acoustic attentiveness** of the watchdogs. In practice, the organization of the working time of dogs in patrol duty should take this into consideration.

- **The individual ability of the dogs to withstand physical loadings is very important for the attentiveness.** The effectiveness of dog dependent guarding systems depends on it.

- **Thoughtless prolonging of the patrol duty time of watchdogs should be avoided both for reasons of animal welfare and their well-being as well as because of the decrease of necessary attentiveness.**

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Untersuchungen über die Auswirkungen motorischer Belastungen unterschiedlicher Intensität auf die Reaktionsbereitschaft von Diensthunden.
Inaugural-Dissertation, Tierärztliche Hochschule Hannover, Deutschland

BASELINE ABRs IN MOUNTAIN SHEEP AND DESERT MULE DEER

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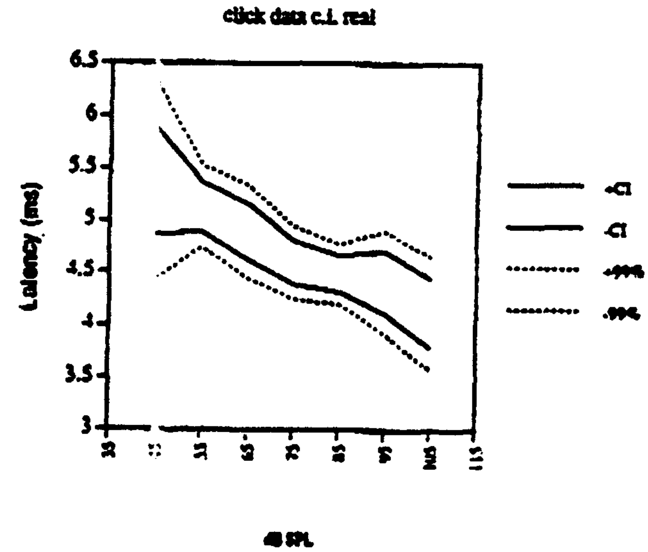
Abstract

The purpose of this study was to develop baseline data reflecting mid-to-high-frequency hearing sensitivity of young adult desert mule deer (Odocoileus hemionus crooki) and mountain sheep (Ovis canadensis). Baseline auditory brainstem responses (ABRs) were recorded from 4 desert mule deer and 5 mountain sheep. Click stimuli and tonebursts were used to elicit ABRs. Animals were sedated and transported from the Wildlife Research Center to the University Health Sciences Center, and lightly anesthetized with halothane during data collection. Thresholds for the various stimuli were determined. Thresholds were best for the click stimulus. The click-evoked wave IV-V complex was reliably present down to 45dB peak equivalent (pe) SPL in sheep and 55dB peSPL in deer. Mean latency-intensity functions and the 95% and 99% confidence intervals were calculated and plotted. The mean slopes of the latency-intensity functions were 20 μs/dB and 32 μs/dB for the sheep and deer, respectively. These are important in understanding the auditory sensitivity of these animals and may serve as a guideline for investigators examining the effects of noise on the mid-to high frequency hearing sensitivity of these animals.



Erratum fig 1 p 253 (vol 2)

SYNOPSIS OF STUDIES ON COMBINED EFFECTS

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Abstract

During the last years many concrete results have been obtained in theoretical issues, in practical research work, in establishing the special periodical in use as well as in international meetings of scientists in the field of studies on combined effects. Besides describing the various studies and the progress involved the author gives a list of typical working stations in small-sized firms where the staff in addition to noises are simultaneously exposed to two, three, four or more work or environment related factors.

Introduction

In the industrial milieu, the staff may be concurrently exposed to a number of agents. Luz (1991) has evaluated that in real-life situations as many as 9 concurrent factors may be observed, with an average of 2.7 simultanous agents. In the industrial report of the Institute for Industrial Medicine this tendency becomes evident, too (Rentzsch et al 1992). Our own recent findings show that small business enterprises have more occupational hazards than medium-sized and large companies, and the work stations of young companies (that have operated 5 years or less) have more often work-related risk factors then old companies (Manninen et al 1993).
Presently there is a growing tendency towards considering the globality of the work environment and potential interactions between physical, chemical, ergonomic and organizational factors. However, the evaluation of effects in combination (combined effects) poses many problems to investigators. To solve these methodological, theoretical as well as terminological problems various attempts have been made very recently. The very latest product of these kind of efforts is the Saariselkä Agreement (Greco et al 1992), a proposal for new definitions for combined action assessments.

Newest Activities

A Periodical on Combined Effects

In particular the complex interaction between and combined effects of various environmental factors, including noises, constantly pose new challenges to research, technical R & D (Research and Development), health care, and of course, labour protection and environmental preservation. There has been increasing demand to systematize the collection of this kind of information and to get a permanent source of reliable and up-to-date information. So in 1989 the Archives of Complex Environmental Studies was conceived with the five missions — distributing information about research applications and methods that are best suited for the study of complex environmental conditions, for R&D, standardization, and environmental regulation and planning and that specifically deal with environment- and work-based loading factors. The periodical approaches aspects of environmental research from the perspectives of different sciences. Today the periodical is a most valuable instrument for the entire range of people working in this field. The Finnish company Aces Publishing Ltd is taking care of editing in cooperation with the internationally distinguished members of the Editorial Board.

International Conferences on Combined Effects

During the last five years two international conferences have been organized. In 1990 the Fourth International Conference on Combined Effects of Environmental Factors (ICCEF 90 Conference) was held in Baltimore, Maryland, USA. In 1992 the Fifth International Conference on the Combined Effects of Environmental Factors (ICCEF 92 Conference) was held in Saariselkä, Finnish Lapland. The primary objectives of these meetings were to discuss fundamental problems in considering health and functional effects of complex environmental exposures including terminology, dose determination, risk assessment, identification of mechanisms responsible for synergistic interaction and to discuss new research findings obtained in this area. Altogether 356 merited scientists from all over the world participated in these two meetings and were given 158 presentations. A major part of the peer-reviewed and accepted abstracts and the original papers have been or will be published in the periodical Archives of Complex Environmental Studies. The sixth ICCEF 94 Conference will take place in Toyama City, in Japan, September 25-29, 1994.

Newest Findings

Subjective Responses

Subjective responses such as annoyance due to noise and vibration, even though their levels are not very high, are major problems in our living and work environments.
A Japanese study (Nakamura et al 1990) revealed that the intensity of annoyance due to the combination of noise and vibration increased with both the increase of noise and vibration.The results also showed that noise had an additional effect on the annoyance induced by vibration. Seidel et al (1990) also points out that both factors, whole body vibration and noise, increase the annoyance if their intensities rise. In addition, interactions between the intensities of whole body vibration and noise have a significant effect on annoyance. In a Swedish study annoyance levels were found to be significantly different between conditions, and they were ranked in the order noise/ vibration, vibration and noise, noise/ vibration causing the highest degree of annoyance (Lundström et al 1990). So Stephens et al (1990) illustrates the very important point that knowledge of both all noise and vibration variables and their interaction effects is necessary in order to properly assess their impact on comfort of any occupants, residents or empolyees. In particular young persons - in comparison to middle-aged or older persons - rated additional stress caused by noise higher when they were doing physically strenous work and were simultaneously exposed to a whole body vibration. The illumination level of general lighting together with smoking affected the experienced stressfulness of the exposure situation (Manninen 1990a). In his other set of experiments, Manninen (1990b) showed that an elevated ambient temperature (30, 35 °C) increased stressfulness in particular where the subjects were exposed to stochastic vibration and noise. Noise, vibration, and physically loading work and their corresponding combinations also influenced tinnitus sensations of the subjects. In general, changes in tinnitus sensations seemed to be associated with the changes in hearing thresholds: the greater the TTS_2 values, the greater were the means of tinnitus rating scores (Manninen 1992).

Changes in Work Performance

Mouze-Amady et al (1991) demonstrated that the highest performance and the lowest physiological cost are found when subjects perform tasks in frontal lighting. At the opposite, working in noise (72-82 dBA) and frontal lighting leads to the worst performance and to the

highest physiological cost. In their assumption, the authors stated that the indirect effects of combined stressors may result from direct effects on the physiological mechanism which modulates the information efficiency. In a Swedish study (Lundström et al 1990) the subjects showed the best performance during a noise exposure of 85 dB(lin). In a Japanese study done by Saito et al (1993) results from a visual reaction tests improved significantly not after noise but after a music exposure at rest in a chair. The same authors conclude that music is a good stressor even in recovery from physical strain.
According to Sandover et al (1990), single stressors appeared to affect performance more than combinations of stressors. The effects of noise were particularly noticeable, speeding up all response times. The combinations of two and three stressors in most cases either diminished or reversed the effects of the single stressors in terms of mean performance time. Noise and vibration as a dual stressor affected consistency of performance serving to make performance less consistent at detecting and identifying vehicles and more consistent at choosing ammunition. Heat speeded up the decoding process, whereas vibration and noise slowed the decoding process down.

Thermal Regulation

Animal studies done by Manninen et al (1991) showed that noise, carbon monoxide and temperature had very significant single effects on the variation of the deep body temperature (dbt) values. Furthermore, the results of the variance analyses showed that the combinations of any two factors had a very significant combined effect on the variation of the dbt-values. Results revealed that 750 ppm CO reduced the dbt-values at 20 °C. The reduction was especially high when the subjects were exposed simultaneously either to a 90 dBA or to a 105 dBA noise. When the dry-bulb temperature was raised to 35 °C and the subjects were simultaneously exposed to noises or simultaneously to noises and 750 ppm CO, changes in the dbt-values were rather small and unsystematic. When the temperature inside the chamber was raised to 40 °C the increase in the dbt-values was the greater the more intense noise was used. In particular when animals were exposed simultaneously to 750 ppm CO and a 105 dBA noise at 40 °C the increase in dbt-values was very significant.
When studying human subjects Schust et al (1991) found that due to noise influence, there is a tendency towards a rise of core temperature within the thermally neutral range. In combination with physical work noise of 90 dBA caused a highly significant increase of mean skin temperatures at 21 °C but an insignificant increase at 33 °C (Borsky et al 1993). In this Slovakian study noise elevated sublingual temperatures of healthy men at 21 °C both as an isolated factor and in combination with physical work load; similar trends were also found at 33 °C.

Auditory and Vestibular Functions

Human Studies

Through a laboratory experiment Manninen (1989) showed that a short but regularly repeated simultaneous noise and vibration exposure accelerates the rise of TTS_2 values at high temperatures (ie 35 °C) considerably more than a noise exposure alone. However, the rise of the TTS_2 values was slightly higher among the non-smokers than among the smokers and at 4 kHz than at 6 kHz. According to Rentzsch and Minks (1989) the greatest hearing threshold shifts occured at the test frequency of 2 kHz related to the combination of noise and the air temperature. The same authors obtained qualitatively similar results for the left and right ear as well as for the other test frequences examined. For the combination of noise and CO

exposure permanent hearing losses (PTS) at 4 kHz in dependence on the duration of occupational activities and age were detected in field tests for welders and machine and plant assembly workers. The exposure combinations had slightly different effects on young, middle-aged and old subjects (Manninen 1990c). The increase of the TTS_2 values at 4 and 6 kHz during the exposure was particularly high when the young subjects were exposed simultaneously to noise and vibration, while they were competing and doing light muscular work. The HDI (hemodynamic index) values correlated more strongly with the TTS_2 values at 4 kHz than with those at 6 kHz. The TTS_2 values at 4 kHz also showed significant correlations with changes in the urine A/NA ratio when young subjects were exposed simultaneously to noise and vibration, and were doing light muscular work and competing.

Prince and Matanoski (1991) suggested that smoking in the presence of long-term moderate occupational noise may potentiate noise-induced hearing loss in humans. Likewise, Mehnert et al (1992) expect that there exists a slightly higher risk for noise-induced hearing loss with respect to the workers exposed to noise and ototoxic agents than for those who are exposed to noise excusively. Results obtained by Morata et al (1990) suggest that exposure to high concentrations of toluene in a noisy environment may greatly increase the risk of developing an occupational hearing loss.
According to Parrot et al (1990) it appears that differences in hearing thresholds for time of day are emphasized by exposure to noise; the most severe auditory fatigue at 6 and 4 kHz is observed at 9 pm. Another French study showed that two minutes after a pink noise of 105 dB had ceased the mean hearing thresholds at 4 kHz reached a significantly lower level in subjects under the effects of alcohol than in noise exposed subjects who had not ingested the drug (Petiot et al 1990).

Animal Studies

Data obtained by Salvi et al (1991) suggested that salicylate does not exacerbate hearing loss or hair cell loss induced by noise. Chinchillas were used in this study. In another American study (Boettcher et al 1989) salicylate administration did not significantly increase the temporary or permanent threshold shift caused by an intense (105 dB) noise. Cispaltin showed a strong interaction with a noise of 85 dB or greater. A whole body vibration with a frequency similar to the resonance of the chinchilla increased hearing loss due to noise by 5 dB or less. In a French study (Campo et al 1992) toluene was not found to potentiate the ototraumatic effects of noise on the cochlea of guinea-pigs.

Other Functional Changes

Behavioral and biochemical findings of Japanese colleagues suggest that both noise and whole body vibration deteriorates changes of emotions with their repetitions, but that the combination in the chronic period does not increase the changes in an additive pattern (Nakamura et al 1991). In another occasion Japanese colleagues suggested that in practical environments with exposure to local vibration, noise and cold are very important factors contributing to emotional changes or deterioration of mental activities rather than local vibration (Nakamura et al 1989). Heart rate and blood pressure are shown to increase significantly after physical exercise together with noise. The decrease in noradrenaline after physical exercise with music was significant, but this was not true for the same condition with noise (Saito et al 1993). In our study post-exposure urine adrenaline excretion rates were explained best by physical work, psychic competition work and age (Manninen 1990c). Noise and age turned out the most important two-factor combination. The most significant three-factor combinations consisted of

Table 1. Most common and typical exposure combinations by observed work tasks in altogether 100 small-sized firms in Central Finland in 1992 (Manninen et al 1993).

Welding	Noise Radiation (light arc, UV) Working posture (lifting) Temperature variation	Lathing	Noise Smells Cutting liquids Working posture (bent) Standing Repeated work stages
	Gases Smokes Radiation (light arc, UV) Noise		Noise Cutting liquids Lighting
	Noise Smokes Dust Working posture (stooping)		Noise Cutting liquids Standing
	Dusts Smokes Lighting Working posture	Polishing	Vibration Noise Draught
	Gases Radiation (light arc, UV)		Dust Noise Working posture
Installation	Weather conditions Danger of falling Noise Working posture (crawling)	Pressing	Noise Muscular work
	Weather conditions Working postures Cooperation with others		Static muscular work Impurities in breathing air
	Weather conditions Lighting Working posture (lifting)	Edging	Muscular work Noise (impulse noise)
	Cold Noise	Tin work	Sharp pieces Noise (impulse noise)
Assembly	Noise Tied to work (supervision, control) Working posture	Beam dimensioning	Noise Smokes (welding) Gases (welding) Radiation Working posture (cutting beams on floor)
	Lighting Working posture		
Reaming	Lighting Noise Crowded space (big objects)	Beam assembly	Gases Temperature variation
Milling	Impurities in breathing air Working posture Lighting	Sheet machining	Noise Dust Paint smells Lifting
	Noise Cutting liquids Standing Tied to work (control work)	Hanging (hanging and pulling down)	Lighting Order Working posture (lifting)

physical muscular work, psychic type competition and noise. The same factors had a significant effect on the excretion of noradrenaline in urine, too.

Typical Exposure Combinations

Most common exposure combinations by type of work tasks in different small metal factories can be listed and summarized as shown in Table 1. This summary shows that besides an exposure to noise both the employees and the employers in modern small sized firms feel the impact of several other adverse working conditions which may be most important in terms of medical wastage (Manninen et al 1993).

Conclusions

As shown here in many situations, human beings and animals are being exposed to mixtures of environmental factors. Exposure to two, three, four, five or more environment-, work- or time related factors can occur simultaneously or sequentially. Exposure to combinations of these agents results in numerous measurable effects. These effects do not only depend upon exposure conditions but also on the structure of relationships between biological processes. When thinking all the scientific activities in this field, a consensus terminology for the joint action of agents is important. The Saariselkä Agreement represents a compromise among widely differing viewpoints. The foundation for this set of terms includes two empirical reference models for the situation in which each agent is effective alone, and in which each agent follows a monotonic concentration effect function increasing or decreasing in the same direction. All the people working in this field are kindly encouraged to get oriented in this document and give the essential feedback for our future work.

In the last conference in Stockholm I strongly underlined that our research has the greater value the more practical applications it can initiate. As shown here, especially, in small sized companies not only workers but also managers are potentially exposed to complex environmental and ergonomic deficiencies. To my knowledge small sized firms do not differ from bigger companies by having a different set of risks. The persistance of risks in small companies is due to the limited skills and resources to eliminate them and due to the attitudes of managers. So people in small firms are a grateful public and they need wise advice. Because small firms play an important role in the local economics all around the world, every activity of ours that supports and promotes profitability of companies is of vital importance to the well-being to all people.

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ANALYSIS OF BRAIN ACTIVITIES TO THE COMBINATION OF NOISE AND OTHER ENVIRONMENTAL FACTORS DURING MENTAL AND PHYSICAL LOADS

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Abstract

Combined effects of noise and illumination on VDT work were evaluated from the changes in brain waves by MEM analysis, somatosensory evoked potential (SSEP), heart rate, urinary dopamine (DA), norepinephrine (NE) and epinephrine (E) excretions, work amount of VDT-task and subjective symptoms of fatigue (SS). Healthy male students were tested under the 4 kinds of *environmental conditions*:700 lx without noise exposure (A1), 700 lx with white noise exposure of 70 dB hearing level (HL) (A2), 300 lx without noise exposure (A3) and 300 lx with white noise exposure of 70 dB (HL). These measurements were performed before, just after and 30 min after or during the one hour VDT-task.

The results showed that differences of delta waves between A2 and A4, beta waves between A1 and A4, and between A3 and A4 were significant, but no significant changes in SSEP and RR variability of ECG were recognized among 4 environmental work conditions. Urinary DA and NE increased significantly in A2 and A3 conditions, and NE recovered at the 30 min. after the VDT work. Number of SS was the most in A3 condition. These results suggest that noise not so high pressure level around 70 dB which is ordinary sounds may be an arousal stimulus to brain activities even in combination with low intensity of illumination.

Key words: Combined effect, Noise, Illumination, VDT work

Introduction

It is recognized that the effects of noise on brain activities differ in accordance with the physical factors of sound pressure level (SPL), frequency, exposure patterns, etc. (Saito 1988). It may be the same as the effects of noise combined with other environmental factors such as air temperature, illumination, etc.. However the combined effects of environmental factors with or without work are not clarified adequately. In the present study how brain activities react to the combination of noise and illumination during mental or physical work was investigated by using maximum entropy spectral analysis of electroencephalograms (EEG), somatosensory evoked potentials (SSEP), heart rate (HR), urinary catecholamines, work amount of VDT and 30 items of subjective symptoms (SS).

Subjects and Methods

Five healthy male students between the ages of 19 and 22 with normal hearing were used in this study. They were performed one hour task with visual display terminal (VDT, NEC PC-9801 na) in an electrically shielded and light controlled soundproof chamber under four kinds of environmental conditions:700 lx illumination without noise exposure (A1), 700 lx illumination with white noise exposure of 70 dB hearing level (HL) (A2), 300 lx illumination without noise exposure (A3), 300 lx illumination with white noise exposure of 70 dB (HL) (A4). Brain waves of these subjects were measured before and after the VDT-task in the chamber in which each subject was placed in a chair with eyes closed and cautioned not to sleep. EEG were recorded by Ag/AgCl disc electrodes attached to Cz, Pz, OL and OR (International 10-20 system) with a electroencephalography (NEC San-ei 1A94). Reference electrodes were placed on both earlobes with a forehead ground. Maximum entropy method (MEM) spectral analyses of brain waves and RR variability of ECG were performed by using MemCalc 1000 (Suwa trust Co. Ltd.) with a microcomputer (NEC 9801-RA) after both EEG and ECG were stored on a magnetic tape by using an FM tape recorder (TEAC XR-70). SSEPs were recorded from C5S-Fz, C3-A1 and C3-Ep1 before and after the VDT-task with 500 times electric stimuli of 3.5- 5.8 mA and 100 ms in duration to right median nerve triggererd at R wave of ECG using a Neuropac (Nihon Koden MEB-4204). Peak latencies and amplitudes for the N13 and N20, and central conduction time (CCT) which is the difference between N13 and N20 were measured. Urinary dopamine (DA), norepinephrine (NE) and epinephrine (E) were measured before, just after and 30 min. after the VDT-task by the method of Anton and Sayre (1962) with some modification with a high-performance liquid chromatography (Shimazu HPLC-34). Heart rate during experiment and SS before and after the VDT-task were also measured.

Results

Power spectra of brain waves analyzed by MEM for each experimental condition are illustrated in Figure 1. The mean and standard error (SE) of accumulated power spectral densities (PSD) of brain waves for each condition and F-ratio in a two-factor (experimental condition × recording time) analysis of variance performed on brain waves are presented in Table 1 and 2 respectively. This analysis revealed that delta and beta waves had significant main effects on experimental condition. The differences of PSD between just after and before the one hour VDT-task in delta wave compared A2 with A4 conditions, and in beta wave compared A1 with A4, A3 with A4, were significant as the results by Student's t test (Table 3).

Peak latencies and amplitudes of N13, N20 and CCT in SSEP showed no significant changes in 4 experimental conditions (Table 4). Although heart rate showed significant changes compared before with during and after the VDT-task (Fig.2), those changes were not significant among 4 experimental conditions.

Changes in DA excretions of 30 min. after the VDT-task showed significant increases in A2 and A3 conditions as compared with A1 condition. Norepinephrine excretions showed the same

increase and recovered at 30 min. after the VDT-task. However E showed no significant changes (Fig. 3). Work amounts of VDT works increased in the order of A1, A2, A3 and A4 conditions.

Total number of subjective complaints of fatigue increased in the order of A1< A2=A4<A3 (Fig.4).

Discussion

Combined effects of environmental factors on brain activities are not always simple. For a example, as to noise and illumination in the present study those effects of noise and illumination may depend upon the intensity levels of these environmental factors, in other words, loudness, noiseness or annoyance of noise and luminosity level. Activation or inhibition of brain activities caused by environmental factors may directly connect to the enhancement and reduction of higher nervous function. High intensity of environmental stimuli to the brain will reduce higher nervous activities. It is very important how combination of more than two environmental factors is effective for improvement of the brain functions.

VDT work is one of visual tasks. Contrast between CRT display of VDT and work environmental illumination is defined by intensity of illumination. It may be supposed that concentration of attention to VDT display enhances under the low intensity of illumination and that not so high intensity of noise around 70 dB(HL) stimulates brain activities in the range of illumination between 300 lx and 700 lx. Increase in total amount of VDT-task, delta and beta wavs of EEG, DA and NE excretions, and less subjective complaints of fatigue under each condition with 70 dB(HL) of white noise or low intensity of environmental illumination may explain such enhancement of brain activities.

Acknowledgements

The author is grateful to the staff of Department of Hygiene and Preventive Medicine, Hokkaido University School of Medicine for their assistance for the experiment and preparation of this manuscript.

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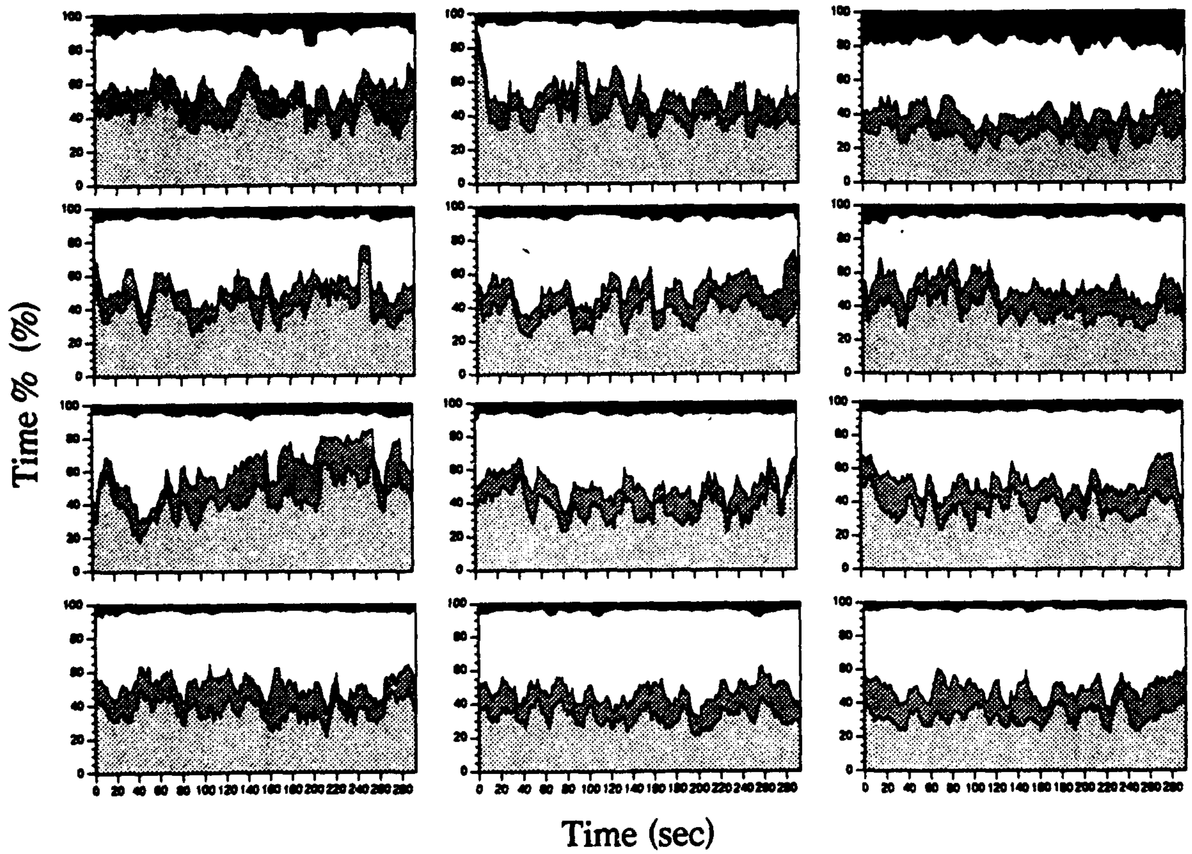

Fig.1 Power spectra of brain waves of left occipital area analyzed by maximum entropy method (MEM) under the experimental conditions for five min. before (left), just after (center), and 30 min. after (right) the VDT-task in Subject A

delta wave, theta wave, alpha wave, beta wave

Table 1 Mean and SE of accumulated power spectral densities of brain waves for each experimental condition (A1: 700 lx, A2: 700 lx + white noise 70 dB (HL), A3: 300 lx, A4: 300 lx + white noise 70 dB (HL)), electrode and recording period (a: before, b: just after, c:30 min. after the VDT-task)

exp.	electrode	record. time	delta mean	delta SE	theta mean	theta SE	alpha mean	alpha SE	beta mean	beta SE
		a	4596844.7	458674.3	5241906.5	663857.8	14364416.9	5533690.9	2074617.3	283277.0
	Cz	b	4107642.5	321084.1	5429237.9	977492.1	15569435.5	5816850.1	2409478.9	396891.3
		c	3937713.3	282408.8	5643710.7	983810.4	14144517.5	4411317.8	2357571.5	293283.4
		a	3765231.5	163154.7	4204462.3	769936.5	13224137.1	5076224.3	1998838.0	229215.5
	Pz	b	3456978.1	363348.7	4576221.5	893786.7	16168100.6	5221093.2	2569098.0	627840.1
A1		c	3466689.5	317825.6	4715846.2	907920.1	16465972.7	4096350.5	2747157.1	608429.4
		a	3174606.5	313692.4	3629442.8	805070.3	13013990.9	5005288.7	3389265.8	981341.3
	OL	b	2806589.8	311604.5	3580888.2	899814.4	13148312.7	4228649.6	2551779.7	542507.4
		c	2826781.6	360437.7	3557228.3	739257.2	13059750.9	3261602.0	3157066.8	539320.8
		a	3197708.7	311501.9	3831389.2	904274.9	10235001.0	3412112.7	2409690.7	392085.9
	OR	b	2947542.8	298806.4	3657947.6	890701.8	10480821.1	2888251.7	2398939.1	528843.6
		c	2877587.7	347768.5	3818824.3	807358.6	11503379.2	2423095.4	2842793.1	433262.6
		a	3901259.8	322603.5	4640396.7	642464.5	14125233.6	4496956.0	2220463.0	342145.5
	Cz	b	4025881.1	291782.2	4962125.5	794938.4	13401956.6	4106475.4	2220308.7	315123.4
		c	4552570.7	415703.9	5102465.9	663572.7	17087133.0	5811903.8	2434275.6	390436.2
		a	3301181.3	288486.7	3878940.2	635720.1	15672808.5	4483842.6	2396321.1	519706.9
	Pz	b	3103110.9	152496.0	3758693.9	582852.4	12980740.2	3464442.7	2405965.3	540016.1
A2		c	3537755.6	172823.8	4252192.5	607619.3	16731670.9	4689830.5	2680382.7	656886.5
		a	2703415.7	296223.3	2954108.1	564790.0	10229013.8	2312783.0	2223922.1	402823.4
	OL	b	2439731.4	205539.5	2703419.2	387697.0	9443610.1	1747756.3	2273060.5	367385.7
		c	2943471.7	281701.2	3138732.9	466335.4	11022856.8	1783880.4	2626681.2	497080.9
		a	2878891.2	365248.2	3225735.6	626910.1	10245680.2	2214882.0	2138771.4	429210.1
	OR	b	2572522.5	228823.9	2849082.2	414844.2	8828287.2	1491959.5	2160240.3	492498.3
		c	2979962.9	309104.7	3389081.9	531770.6	10696631.0	1845383.3	2232505.9	479325.3
		a	3840779.0	289763.3	4531101.5	735350.4	9616536.7	2440362.2	2023109.3	414029.7
	Cz	b	3541424.9	451921.7	4963701.5	863867.4	12871078.9	3630329.6	2153916.2	304446.1
		c	4149406.2	432391.6	5461717.0	747613.7	13645860.9	3490972.8	2532913.0	381617.6
		a	3136422.1	336786.4	3575724.9	518285.7	11378212.9	2363657.4	2236549.9	652491.3
	Pz	b	2866558.0	384812.4	3724405.3	647785.7	13272459.1	2880689.6	2190182.8	486158.0
A3		c	3259778.8	409918.3	4090908.1	591637.7	13986405.6	3023929.8	2579059.7	588916.8
		a	2446675.4	369900.3	2841195.5	497205.0	8960475.8	1903786.5	2178141.3	525984.8
	OL	b	2395569.5	369576.5	2845835.9	530419.9	10376485.3	1938987.1	2035382.2	331841.0
		c	2615241.3	445854.4	3153165.5	601979.4	10214580.1	1980878.4	2261705.4	465194.6
		a	2768481.3	387830.1	3251846.1	525752.4	9452700.0	1922476.0	2321157.9	691385.7
	OR	b	2667698.3	381928.9	3202624.8	581016.8	11307373.6	2312476.2	2092996.6	463043.2
		c	2976488.9	482878.2	3696058.5	671598.8	11031761.2	2170905.3	2421926.6	556059.3
		a	4168802.1	535948.2	5549427.5	1258499.7	11915834.9	2979149.0	2284839.1	484355.8
	Cz	b	4406132.9	632357.9	6606370.0	1600916.0	14450763.2	3938718.7	2442956.7	398961.8
		c	5507024.1	842106.8	6837758.2	1595073.4	14078768.2	3886849.2	2478092.5	433777.7
		a	3452625.6	641369.3	4631244.6	1148194.8	15660594.8	3441419.8	2278923.0	577340.2
	Pz	b	3682843.2	737113.1	5457863.2	1537256.1	17396836.1	3899749.1	2521126.9	599752.6
A4		c	4225991.1	681041.3	5815768.7	1742811.8	19837030.7	4069150.0	2435716.1	497852.2
		a	2498717.3	446706.2	2920463.7	665568.2	11502418.7	2175822.8	1727181.3	204012.0
	OL	b	2686094.4	488862.5	3312823.0	790749.7	12386735.0	2466985.9	2370574.2	413856.0
		c	3030916.5	455187.0	3544720.0	859420.4	13646517.8	2735938.6	1772055.3	114767.8
		a	2652381.1	328389.0	3294232.0	580222.4	11179114.6	1880641.3	1911597.0	370770.3
	OR	b	2907763.1	367179.5	3604622.4	682607.2	11188699.5	1326698.6	2154674.8	440533.1
		c	3293607.0	302392.1	3849911.5	710837.6	12572463.5	1581351.7	1990641.2	287612.9

Table 2 F-ratio of brain waves in a two-factor (A: experimental condition ×B: record -ing time) analysis of variance

electrode	factor	df	delta	theta	alpha	beta
Cz	A	3	1.64	0.52	0.30	0.10
	B	2	0.04	0.06	0.03	0.02
	A × B	6	0.03	0.01	0.01	0.01
Pz	A	3	1.77	0.67	0.25	0.06
	B	2	0.12	0.04	0.01	0.06
	A × B	6	0.05	0.03	0.02	0.05
OL	A	3	3.20*	0.57	0.67	2.86 *
	B	2	0.06	0.03	0.05	0.03
	A × B	6	0.02	0.01	0.02	0.21
OR	A	3	1.27	0.29	0.10	0.25
	B	2	0.05	0.01	0.08	0.01
	A × B	6	0.05	0.01	0.03	0.03

df : degree of freedom, * : significant at $p<0.05$
Factor A , B mean experimental condition, recording time respectively.

Table 3 Comparison of differences between just after and before (a), 30 min. after and before (b) the VDT task, of accumulated power spectral densities of brain waves (delta and beta waves) recorded from left occipital area in each of experimental condition

exp.	delta				beta			
	a		b		a		b	
	t - values	sig.	t - values	sig.	t - values	sig.	t - values	sig.
A1 vs. A2	0.241	N.S.	1.453	N.S.	1.521	N.S.	0.382	N.S.
A1 vs. A3	0.684	N.S.	0.665	N.S.	1.113	N.S.	0.576	N.S.
A1 vs. A4	1.293	N.S.	1.022	N.S.	2.279	P<0.05	1.534	N.S.
A2 vs. A3	0.945	N.S.	0.798	N.S.	0.651	N.S.	0.431	N.S.
A2 vs. A4	3.178	P<0.01	0.429	N.S.	1.716	N.S.	1.845	N.S.
A3 vs. A4	1.101	N.S	0.366	N.S.	1.909	P<0.05	1.601	N.S.

Values are calculated by Student's t test

Table 4 Changes in short latency (N13, N20) somatosensory evoked potentials in four experimental conditions

exp.	recording time	latency			amplitude
		N13	N20	CCT	N13-N20
A1	before	12.72±0.22	19.53±0.32	6.81±0.35	1.72±0.12
	just after	12.58±0.25	19.24±0.36	6.65±0.46	1.52±0.15
	30 min. after	12.71±0.25	19.43±0.39	6.67±0.46	1.28±0.18
A2	before	12.61±0.22	19.39±0.32	6.77±0.33	1.76±0.18
	just after	12.53±0.22	19.26±0.30	6.73±0.29	1.80±0.20
	30 min. after	12.66±0.25	19.39±0.42	6.73±0.37	1.64±0.19
A3	before	12.72±0.21	19.59±0.29	6.87±0.33	1.84±0.13
	just after	12.62±0.19	19.67±0.30	7.05±0.25	1.88±0.21
	30 min. after	12.66±0.22	19.59±0.30	6.93±0.32	1.68±0.15
A4	before	12.62±0.20	19.55±0.28	6.93±0.25	1.61±0.15
	just after	12.70±0.28	19.47±0.29	6.77±0.26	1.51±0.24
	30 min. after	12.74±0.28	19.46±0.30	6.71±0.35	1.57±0.05

CCT : central conduction time

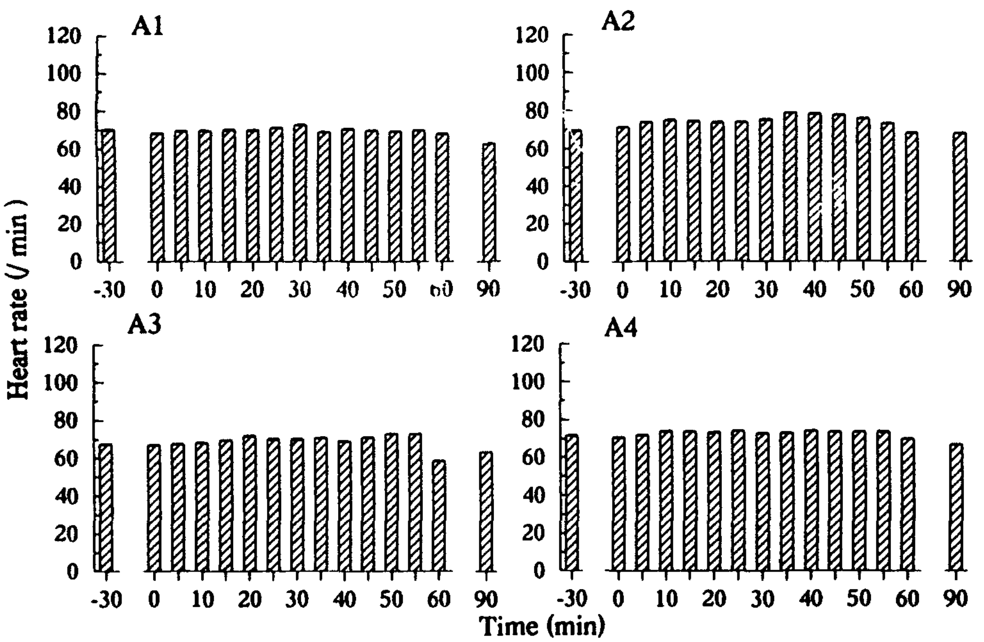

Fig.2 Comparison of mean values of heart rate for five min. in different experimental conditions (Mean ± SE)

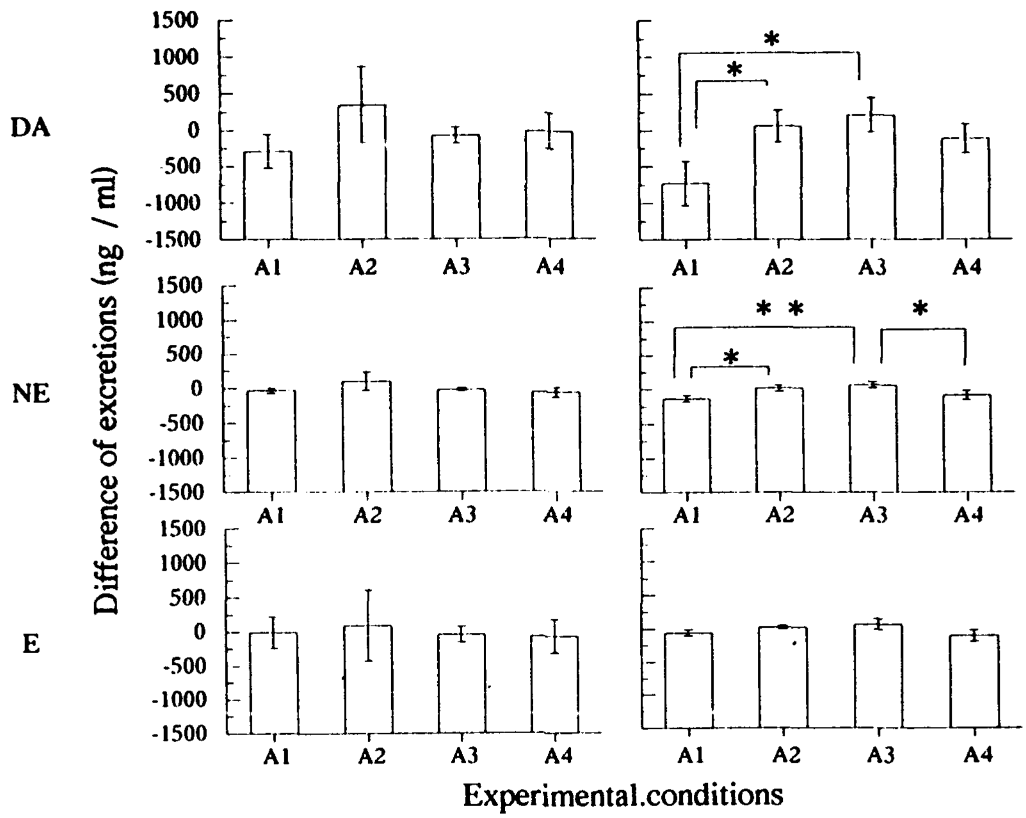

Fig.3 Comparison of differences between just afetr and before (left), 30 min. after and before (right) the one hour VDT-task, of dopamine (DA), norepinephrine (NE) and epinephrine (E) excretions in urine (Mean ± SE, * p<0.05, ** p<0.01)

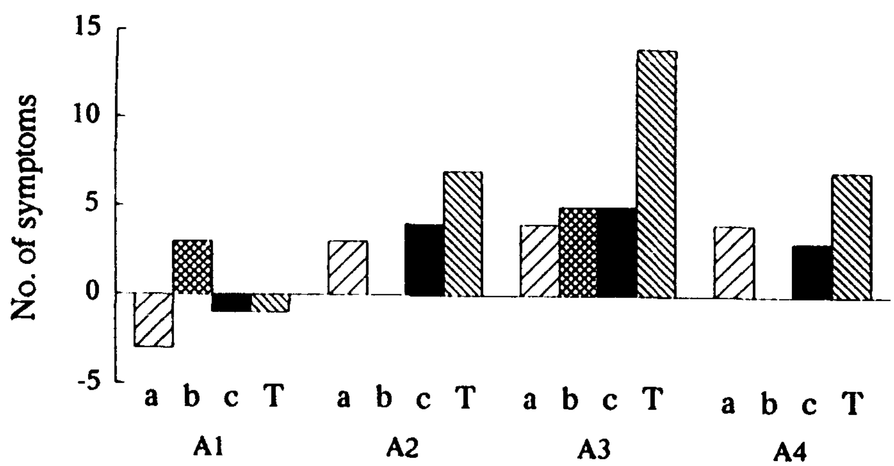

Fig.4 Changes in subjective symptoms (a: physical, b: mental, c:neuro-sensory, T: total)before and after the one hour VDT work in different experimental conditions

CHANGES IN BRAIN FUNCTIONS DUE TO NOISE AND ITS COMBINATION WITH BRAIN AFFECTING SUBSTANCES

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ABSTRACT

In animal experiments using chronically implanted electrodes specially constructed for DC-recordings information related as well as intensity related cortical DC-shifts to noise and sounds were recorded. The DC-shifts during a 28 sec exposure to a series of physiologically meaningful sounds (battle cries) were compared with the reactions to an energy equivalent white noise. The white noise lead to a smaller on-effect and an earlier return to the baseline. In combination with the influence of CO this return to the baseline was accelerated especially in the condition with meaningful sounds.

Concerning auditory evoked potentials · carbon monoxide (CO) and nitric oxide (NO) prolonged the latencies of the P_{10} and N_{30} components and increased their amplitude. At high exposure levels the combined effect of CO and NO to N_{30} was overadditive.

In recent experiments the interactions of a substance affecting the cholinergic septo-hippocampal pathway (Ethylcholine Aziridinium, AF64A) with auditory evoked potentials and noise as well as sound induced DC-shifts were studied. In contrast to CO and NO the substance AF64A shortened the latency and reduced the amplitude of auditory evoked potentials.

Under the influence of the investigated substance (AF64A) which produces cholinergic lesions similar to Alzheimer's disease, the amplitude of spontaneous EEG was reduced and a diminution and shortening of sound induced reactions was seen. Moreover under AF64A the differences between meaningful sounds and white noise nearly disappeared.

In human studies, combined effects of street noise and white noise with mental stress on cortical DC-potentials are demonstrated. The results are interpreted in the sense of a hierarchical system of activation.

1. Introduction

Brain functions during information processing may be evaluated by recording the electrical activity of the brain at different levels of specificity. Spontaneous EEG-activity, evoked potentials, slow potential waves and DC-shifts may change in rela-

tion to concepts of activation and behaviours. A hierarchical system of activation was proposed in this connection (Haider et al., 1981).

The effects of noise- and sound-induced changes in cortical brain function under physiological conditions as well as in combination with different brain affecting substances will be demonstrated in this paper.

2. Materials and Methods

Special agar-imbedded Ag/AgCl sintered electrodes were chronically implanted epidurally over the prefrontal and parietal regions of both hemispheres of rats, and the reference electrode was fixed over the nose bone. In an operant chamber, the rats were exposed to a series of battle cries with a mean frequency of 24 KHz, 90 dB, lasting 28 s. The battle cries were registered with a tape recorder during fights between rats. For comparison an energy-equivalent series of artificial sinustone-stimuli was presented. The rats were also exposed to "Extreme Vocalizations" (8KHz, 90 dB, 0,8 sec) which were registered as a rats cry, when being snapped by a snake in a zoological garden.

To test the influence of different substances on noise- and sound-induced changes, rats were either exposed to CO (100 ppm, 500 ppm), NO (10 ppm, 50 ppm) or a CO/NO combination or were treated with AF64A (intracerebroventricular injection of 2 ml/ventricle).

3. Results

3.1 Combination effects of sound and noise with carbon monoxide (CO) on cortical DC-shifts.

The DC-shifts during the 28-s-exposure of the rats to 90 dB series of battle cries resulted in a shift of about 70 µV over the whole exposure time with clear on- and off-effects. The energy-equivalent artificial tone-series led to a smaller on-effect and the curves returned to the baseline, before the acoustic exposure time ended. The amplitude of the on-effect as well as the DC integral were significantly different (Mann-Whitney U-Test, $p < 0.05$).

Under the influence of CO, the DC shifts, which in normal air last over the whole exposure time of 28 s, are apparently changed. There is a clear on-effect at the onset of the noise, but after a few seconds the DC shift is ended. The CO effect, if added to a biologically meaningful acoustic stimulation, made the stimulus-induced DC shift similar to the energy-equivalent artificial tone series (Haider et al., 1990).

3.2 Effects of combined exposure to nitric oxide and carbon monoxide on acoustic evoked potentials.

In a series of animal studies the combination effects of carbon monoxide and nitric oxide on acoustic information

processing were analysed (Groll-Knapp at al., 1988). In this study the interactions were investigated at different effect levels. This included blood parameters (carboxyhemoglobine and methemoglobine) as well as centrally mediated effects studied on cortical acoustic evoked potentials and on behavior in a complex discrimination learning experiment. On the level of carboxyhemoglobine and methemoglobine formation only interactions occured which disappeared with prolonged exposure. But the behavioral effects as well as the effects on the acoustic evoked potentials were additive at lower CO and NO concentration and hyperadditive at higher ones.

Nitric oxide (NO) was the dominant factor in these experiments, since in combined exposure conditions the NO-specific changes predominated and were even further enhanced. This prominent influence of NO on brain functions may be related to the recently discovered role of NO as transmitter substance in the brain.

3.3 Combined effects of a substance affecting the cholinergic septo-hippocampal pathway (Ethylcholine Aziridinium AF64A) with sound and noise.

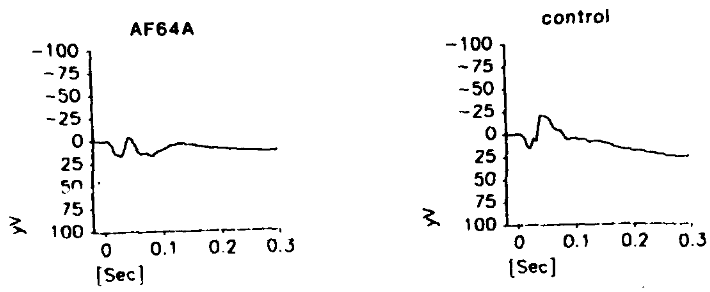
Since cholinergic mechanisms are supposed to play a vital role both in the genesis of slow DC potentials and in memory function, we also intended to answer the question to which extent cholinergic mechanisms contribute to the electrical brain responses. For this purpose the responsiveness of young adult or aged rats with a specific lesion of the septo-hippocampal cholinergic system induced by the neurotoxin AF64A was studied. AF64A has been demonstrated to decrease selectively and persistently presynaptic cholinergic markers in the hippocampus following intraventricular administration (Hörtnagl et al., 1987).

3.3.1 Auditory evoked potentials

Typical average auditory-evoked potentials (AEP) in rats are shown in Fig. 1. The AEP's are characterized by multiple positive and negative components.

Fig.1: **AUDITORY EVOKED POTENTIALS**

in AF64A treated animals and controls



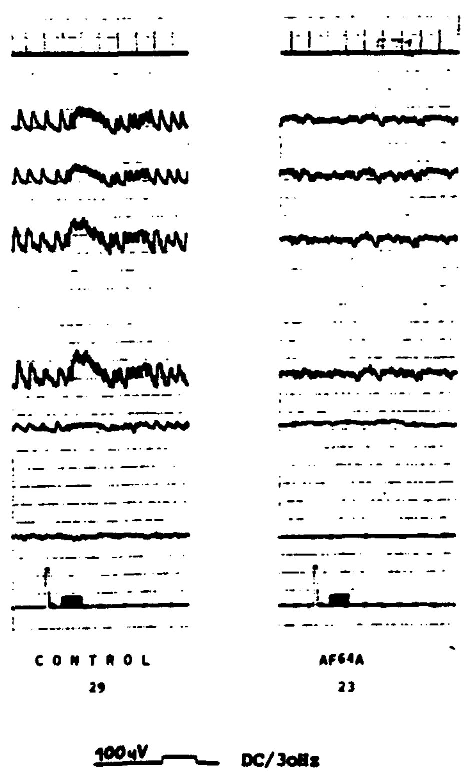
Amplitude values and latency measures of the main negative component were analysed statistically. Analysis of variance with the factors age (young/old) and treatment (AF64A) revealed a significant main effect for treatment: The evoked potentials component of AF64A treated animals was dramatically decreased as compared to controls and had a somewhat shorter latency.

3.3.2 Interactions of Ethylcholine Aziridinium with biologically meaningful sounds.

Biologically meaningful stimuli (extreme vocalizations of rats when being snapped by a snake) evoke very high and long-lasting DC shifts at all recording sites.

In control rats this potential shift is characterized by an on-effect followed by a steep positive going shift of high amplitude which slowly returns to baseline. The positive shift outlasts the duration of the cry for many sec. Fig. 2 demonstrates the EEG and the influence of extreme vocalizations in AF64A treated animals and controls. The great differences are evident. AF64A treated animals have a smaller initial positive shift which returns to baseline earlier.

Fig.2: **INFLUENCE OF AF64A AND ITS COMBINATION WITH EXTREME VOCALIZATIONS ON THE EEG**



In a principal component analysis 3 components could be identified. A P300 component (peaking around 300 msec but lasting up to 2 seconds), a slow wave component (between 1 and 8 seconds after the extreme vocalization) and a slow shift component starting about 5 seconds after the stimulus onset and lasting about 10 sec.

Table 1: **PRINCIPAL COMPONENT ANALYSIS**
FACTOR VALUES

RESULTS OF ANOVA
AGE x SUBSTANCE x SOUND

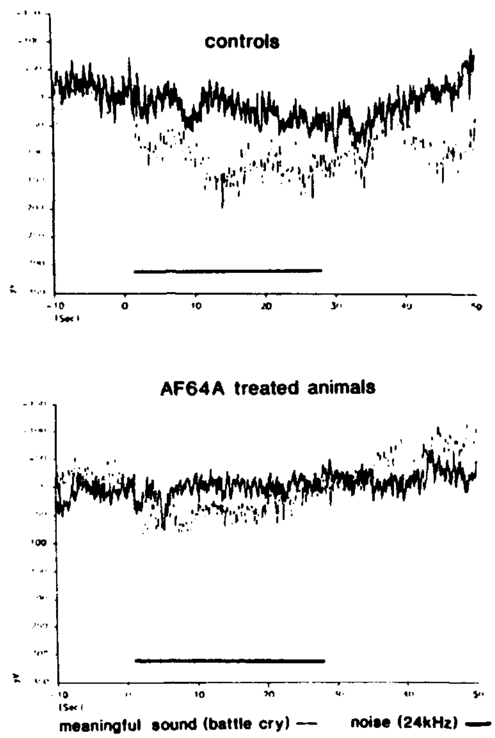
	P 300	SLOW WAVE	SLOW SHIFT
1 AGE	p .46	p .34	p .31
2 SUBSTANCE	p .02 •	p .01 • •	p .72
3 SOUND	p .98	p .05 •	p .23
SIGNIFICANT INTERACTIONS			1x3 p .04 •

Factor values were compared by ANOVA (Table 1): Treatment with AF64A resulted in a significant diminution of the P 300 and the slow wave component. Extreme vocalization and white noise evoked significantly different factor values only for the slow wave component. However, the lowest slow wave factor values were calculated for AF64A-treated rats in white noise condition. Significant effects of the substance (AF64A) resulted in a diminution of the P300 as well as the slow wave component. The sound influence (extreme vocalization as compared to white noise) works in the same direction only in the slow wave component. A significant interaction between age and sound was found for the slow shift: the difference between noise and sound was more pronounced in young rats.

3.3.3 Combination effects of sounds and noises with Ethylcholine Aziridinium on slow potential shifts.

The same 28 sec exposures of rats to a 80 dB series of battle cries as used in the CO study were used in the study with AF64A. The results are shown in Fig. 3. Again a clear on effect to the sound is shown as well as a DC-shift over the whole exposure in the control animals. A diminution and shortening of these brain reactions occurs in the AF64A treated animals.

Fig. 3: SLOW POTENTIAL SHIFTS IN RESPONSE TO BIOLOGICALLY MEANINGFUL SOUNDS AND ENERGY-EQUIVALENT NOISE

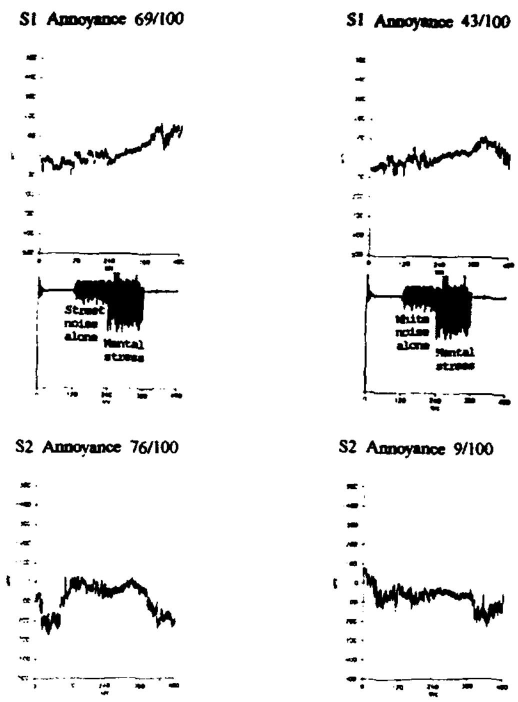


4. Combined effects of street noise and white noise with mental stress

In Fig. 4 the combined effects of street noise and white noise with mental stress on cortical DC-Potentials are shown. This study is still in progress and we use these EEG-curves of 2 subjects to demonstrate that DC-Potentials over longer periods (in our experiments 8 min) may be useful for the study of combined effects of noise with other factors.

It may be seen in fig. 4 that street noise produces higher DC-potentials in the brain than white noise and that the combination with mental stress enhances this effect. But we must state in this connection, that great individual differences exist and that the curves on fig. 4 are only presentations of 2 subjects taken out of an ongoing study.

Fig. 4: **Street noise** **White noise**



Combined effects of Street noise and White noise with mental stress on cortical DC-Potentials (2 Subjects with different annoyance ratings).

5. Discussion

The presented data demonstrate that the combination of sounds and noise with brain affecting substances has differential effects on brain functions. These effects include changes on different integration levels like amplitude decreases and frequency changes in the spontaneous EEG activity. Amplitude and latency changes of evoked potentials and changes in late potentials (P300) as well as slow wave components (lasting some seconds) and slow shift components (lasting some minutes). Some results may at the present state of science best be explained by a hierarchical system of brain activation (Haider et al., 1981). Extreme vocalizations for instance enhance

general as well as tonic phasic, and selective activation processes. AF64A a substance which produces cholinergic lesions similar to Alzheimers disease in the rats brain, diminishes the phasic and selective activation processes whereas at the same time the general and tonic activation is enhanced. On the other hand during exposure to CO and/or NO the phasic activation processes are increased.

What we need in the future is a better theoretical and neuroscientific framework for the combined influence of sounds, noise and brain affecting substances on brain functions including electrophysiological as well as morphological and biochemical parameters.

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NOISE AND VIBRATION AS INDICATORS FOR USING EXPERIENCE BASED KNOWLEGDE

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1. INTRODUCTION

Many forms of experience-based knowledge originated in the past from the perception by the skilled worker of process indicators in conventional machinery. This perception could be of a visual, acoustic, olfactory or tactile nature (Fig. 1). The encasing of the CNC-machine, whilst desirable from the point of view of safety, hinders the perception of such indicators and restricts the relationship of the machine operator to the process. For this reason, it is now a matter of concern to "reopen" the machine to achieve greater process transparancy without breaching work-safety and work-hygiene principles (Rentzsch 1990).

This report deals with initial measures for the improvement of acoustic perception.

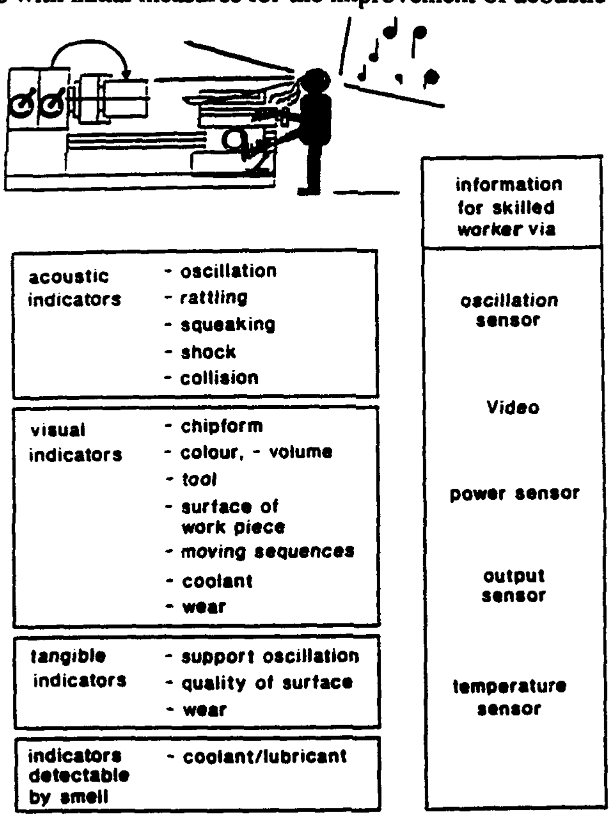

Fig. 1: Possibilities for man - machine - communication

2. QUESTIONS AND HYPOTHESES

Owing to the use of cooling lubricants in characteristically highspeed CNC-machines, process control by visual means is greatly restricted, so that the machine operator is dependent on other indicators. The skilled worker controls the operation acoustically, his ear being tuned to the correct tone - a sound which, however, he is unable to describe in words (Böhle et al., 1991). He may also make use of indirect information provided via oscillation and / or structure-borne sound sensors attached to the machine (e.g. on the tool).

The perception of such acoustic indicators is, however, seriously impeded in most modern machines, with the result that empirical research has led to the conclusion that " if you can hear it, it is already too late ". One of the main reasons for this consists in the machine-tool sound-insulation strategies adopted in recent years. From the point of view of experience-based work the question must be raised whether there are sound elements which can reveal important information and can thus serve as direct indicators for the machine operator.

A second major hindrance to perception of processing sounds is the overlay of sound emissions from various sources in the machine. Masking means that these sounds, some of which could supply more, and some less, relevant information about the process, are perceptible only to a limited extent, if at all. Hence, the alternative means of controlling the state both of machine and process (e.g. tool erosion) using oscillation sensors is an important supplement.

3. NOISE IN CNC-MACHINE TOOLS

In order to make use of worker-experience in the operating process, attention must be paid to those sources producing sounds which either supply the operator with information about the conduct or condition of the process, or which impede the perception of such information.

As part of the research project entitled "Computer-aided experience-based work" (CeA) qualified machine operators (with the skilled worker's certificate "Facharbeiterabschluß") at 19 workstations in 5 companies were interviewed on certain aspects of the improvement of process transparancy through structural alteration to the machine. The interviews revealed the great influence of the machine's structure on the operators' subjective assessment of the degree of process transperancy at their respective workstations. In particular where acoustic indicators are consemed, the type of encasement of the working area is of special significance. Almost no complaints were heard about limited accessibility to acoustic indicators on old milling machines on which the work bench was completly free of encasement and was only fitted when required with small panes of glass to catch flying shavings. By contrasts, almost all workers complained about loss of important information when working with more modern milling machines, and, in particular, with turning machines. These results indicate that the type of encasement of the working area is a serious problem.

Further very important factors are the type of production and the tasks to be performed. In general it can be stated that the interest shown by skilled workers in such structural alterations is stronger in small-scale and single-piece production units than in mass and large-scale production units.

On the basis of the above-mentioned interviews with CNC-machine tool operators, as well as laboratory experiments, the following sound sources on machine tool were localised and analysed:

Processing sound:
This sound provides the machine operator with a great deal of relevant information and is therefore subjectively assessed as highly significant and, in most cases, too quiet.

Hydraulic equipment
Almost all operators agreed that they could gain almost no useful information from the hydraulic sound sources, and that this noises was a major hindrance to the perception of the processing sound. Moreover, the noises was experienced as highly unpleasant.

Main driving motor:
When the program is running the operator can estimate from the sound emissions of the main driving motor the approximate speed and, hence, in some cases the current stage in the program. This is used mainly when the operator is responsible for several machines and is, thus, unable to stand directly next to the machine. Usually, however, this noises is not used for obtaining information, since this can be gained at least as quickly and reliably from display elements and other indicators. It serves only as a rough guide, for instance to distinguish between drilling, thread skiving, transverse or linear turning. The perception of the processing sounds is, however, greatly impede by the noise from the main driving motor.

Opereating sounds from the tool changer
These sounds are also a very rough guide for the operator regarding the stage reached in the program, and they can be perceived with varying levels of intensity on the different machines. Since they occur only when processing is not in progress they do not impede perception of either processing or path feed sounds. For this reason, they were not considered in detail.

Other sound sources:
A CNC-machine tool has a large number of other sound sources (e.g. shavings extractor, path feed sounds from the slide during processing, and other auxiliary drives), which, however, make up only a small proportion of the total noise level, or which do not coincide with the processing sounds and therefore not relevant in this context (Fig. 2).

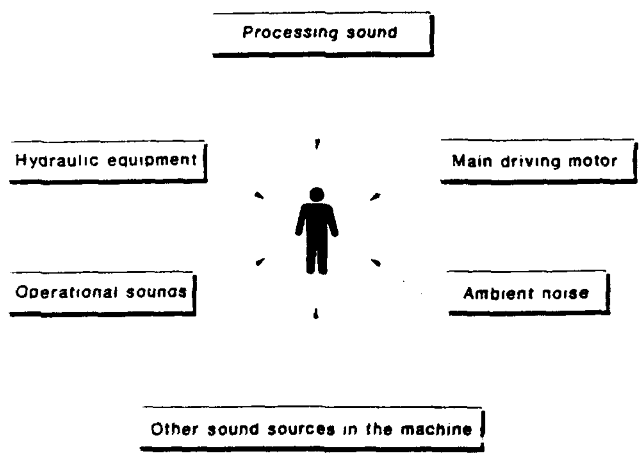

Fig. 2 : Noise components in machine-tools

4. METHOD

In order to state more precisely in physical terms the observations of the skilled workers, and to find a starting point for improvements to the perceptibility of direct acoustic indicators on CNC-turning machines, it was necessary to analyse the frequency characteristics of selected sound sources on several machines in different processing situations, and, on the basis of the resulting spectra, to assess the hypotheses concerning the hindrance of acoustic perceptibility.

The method used was as follows:

So that values for various machines could be optained under truly relevant conditions, measurements were taken not only in the laboratory, but also in the real workshop situation. However, since frequency analysis is difficult to perform under such conditions the sounds were recorded digitally and assessed in the laboratory. The equipment used consisted of a Robotron (now AST Dresden) analogue frequency analyser type 01 012, an Onkyo R1 digital recorder, a Robotron sound level meter type 000 017 and a Bruel & Kjaer module sound level meter 2231. Recordings were made for two production situations in laboratories at Dresden University of Technology, and in the workshops of three companies, each with two characteristic types of production. Measurements were taken on the following machines:

* in the laboratory on one WMW NILES DFS 2 machine and on one Gildemeister CTX 400 machine,
* in the workshops on two WMW NILES DFS 2 machines.

Measurements were taken at different points on each machine, mainly at the position of the operator in the following operating states :

* with hydraulic equipment in operation (a and c)
* with main drive in operation (b and c)
* during processing (c).

Comparison of the recorded spectra was expected to confirm the hypothesis about the mutual overlay of the individual sound sources and to reveal the origin of the emissions in the individual frequency bands. Recording of the sounds also made possible the analysis of the chronological sequence of processes within the respective frequency bands.

Preliminary investigations showed that octave analyses are too inaccurate for the purpose in hand, and that narrow-band analyses with a band width of 10 Hz are a great deal more time-consuming whilst producing little more in the way of findings than a Terz analysis. Hence, all frequency analyses were conducted in Terz bands.

This method would appear to be adequate for investigations concerning experience-based work and for initial confimation of the hypotheses. In order to solve the problems of machine noise, it will, of course, be necessary to conduct much more extensive research (e.g. selective seperation of sound sources, and measurements according to the DIN 45635 ff. enveloping surface method).

A further method of process control available to the machine operator is the recording and transmission of signals relating to vibration and structure-borne noise from the tool.

The psycho-acoustic properties of structure-borne sound are expected to be similar to those of the airborne sound of non-encased machines. The phenomenon can be explained by the fact that the airborne sound results from a better acoustic propagation of the emitted structure-borne sound, than that of encased machines.Skilled workers confirmed this assumption , i.e. body-borne sound increases the emotional connection with the working process. Nevertheless, concerning orientation there was the need to change one's view. The same process could be

observed when workers changed from a conventionally non-encased machine to an encased machine.
If an intelligent diagnostic system is installed, tool erosion or breakage can be anticipated and avoided by changing the tool (Fig. 3).

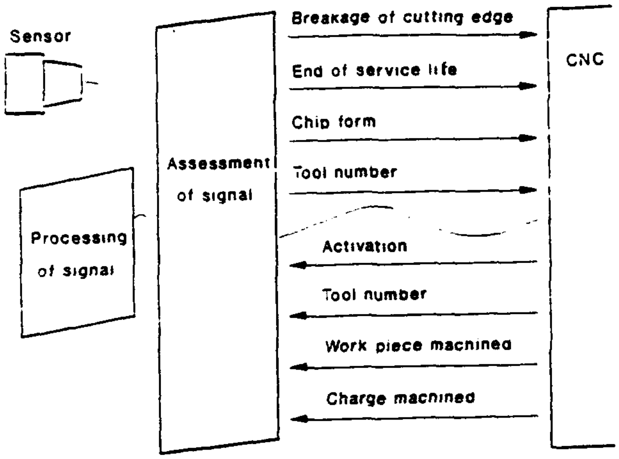

Fig. 3 : Structure of an intelligent diagnostic system

Process control is conducted using the illustrated informational exchange between the machine control system and the integrated monitoring system.

5. RESULTS AND THEIR INTERPRETATION

The ability of the machine operator to perceive directly the processing sound is, naturally, heavily dependent on the material to be processed, the resultant speeds and the type of processing involved. On the basis of the measurements obtained, a selection of observations will be presented below:

Linear turning of free cutting steel:
There is very little difference in the noise level produced by processing, by the hydraulic equipment and by the main drive, so that the sounds of the individual units can hardly be distinguished and are perceived as a single noise. (In psychoacoustics, it is generally accepted that a difference of 3 dB is required between sounds in order to distinguish them reliably) (Fig. 4). In the lower frequency bands it is clearly the hydraulic equipment that determines the total noise, with the result that the low-frequency processing sounds (up to approx. 150 Hz) cannot be perceived.
Due to research work on the above-mentioned project an important reason for the loss of acoustic information could be determined. An intensive echo effect located at various machines seems to be definitely accountable to the hindering to psycho-acoustic perception. Finally, we can say that the acoustic properties of the investigated machine encasements had been unfortunately neglected (Fig. 5).

Measurements using the structure-borne sound sensor
The chronological planning of prophylactic maintenance can be deduced from the oscillation values obtained during operation. The recording of the intensity of structure-borne noise makes possible the diagnosis of tool breakage and flaws in the material.

The frequency distribution of the signals for structure-borne noise provide important clues concerning the state of both machine and tool.

On the basis of these measurements it can be stated that:

i) In almost all the machines tested, the hydraulic equipment produces an acoustic pressure level in the 60-800 Hz band, which below 250 Hz impedes the direct perceptibility of the processing sound.

ii) The noise emitted by main driving motor is, of course, dependent on its speed; this means that in the cource of an operating program with a constant average speed, it is subject to major fluctuations.

iii) The perceptibility of the processing sound in its entire spectral composition is seriously impeded not only by noise interference, but also by machine casing.

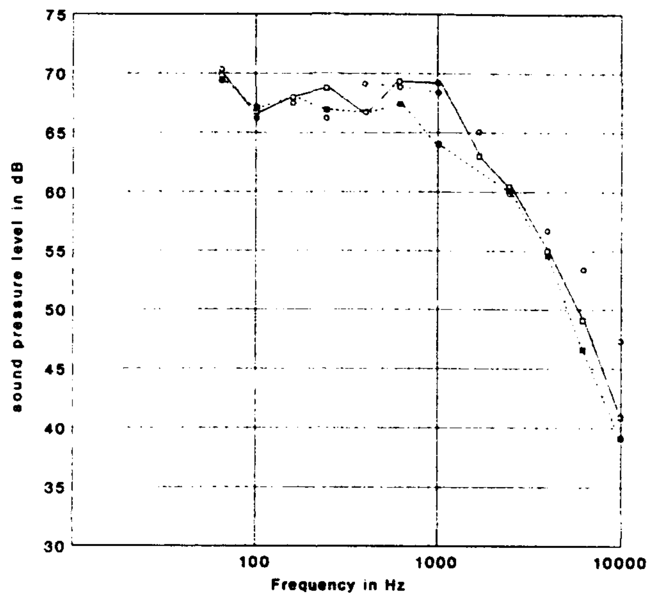

Fig. 4 : Frequency characteristics in various operational states during the processing of steel
- Sound emitted by hydraulic equipment while machine at standstill (point c)
- Sound during operation (point c)
- Sound emitted by hydraulic equipment and main driving motor at a speed of n = 490 min $^{-1}$ (point c)

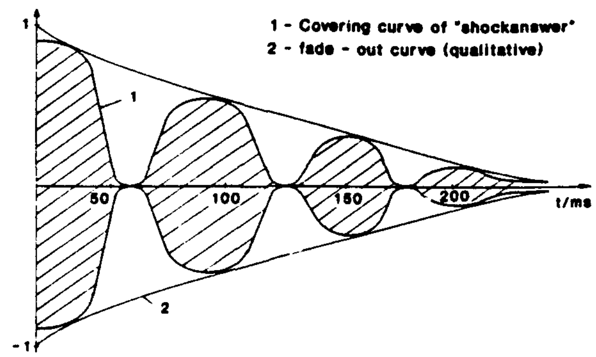

Fig. 5 : Qualitative representation of covering curve of the transfer function in the time range (echo effect)

6. CONCLUSIONS

These measurements confirmed the empirical findings made by the above-mentioned CeA research group regarding the impeded perceptibility of direct acoustic process indicators, and determined its causes. There are several ways in which the situation could be improved. The main goal must be the improvement of the audibility due to the frequency and time structure of the processing sound. This is possible by means of an acoustic design of the processing area guaranteeing the transmission of the most important acoustic informations based on reflecting and absorbing measures.
A further way would be use of improved noise insulation technology in the two main sources of noise.

Hydraulic equipment:
Noise insulation on the trim panels of this equipment would be possible, involving their coating with sound-absorbent materials (Rentzsch, 1962). This would require consideration of the problems of heat build-up and the reduction of the sound pressure level in the low-frequency bands.

Main driving motor:
Because the noise emitted by this equipment is heavily dependent on its running speed, specific noise reduction measures would be feasible only in certain operational states.Further research will be necessary to determine whether this would be worthwhile, and if so, in which operational states. Another method of improvement would be the enhanced perceptibility of the processing sound for the skilled machine operator. The importance of the acoustic perception of direct process indicators varies according to the stage in the program. The operator would like the option of being able to listen to sounds produced in the processing area . The relatively short periods of exposure to the noise, in association with improved insulation of other machine units, mean that it would be acceptable to do without the soundproofing effect of the encasement for certain periods of time. For this purpose, a double door is currently being developed. Owing to the observation that, in order to compensate for lacking process transparency, machine operators frequently leave the door to the processing area open during running-in or go to openings in the machine encasement during operation, it is important that the new measure should harmonise the desired process transparency with technical safety requirements. During the relevant periods the operator should be able to push aside the inner parts of the encasement and thus remove acoustic barriers without danger (Kullmann et al. 1992).
In future experiments it is intended to produce processing situations in CNC-machines in which the operator is required to perform certain actions. Digital signal processing procedures will be used to simulate situations with program-controlled signal display and with signal removal for testing with experienced skilled workers. The changes in the recognition by the workers of various processing situations will enable conclusions to be drawn regarding the relevance of certain frequency bands and sound patterns, and hence, provide further information to help improve the encasement of machine tools. Improvements made in the perceptibility of direct acoustic indicators through such methods are, in many cases, a sensible alternative to far more complicated and expensive solutions to the problem such as the installation of sensors.
This is the case, in particular, when the machine is to be progammed and the graphic programming system is not sufficient, thus rendering important the direct audibility of sounds.

If monitoring and control are related to a combination of CNC-machines and conventional machines, as in multi-machine operation, individual sources of noise cannot be localised due to noise interference. In such situations, the comparison of airborne and structure-borne sound signals is important for the machine operator.

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NOISE AND COMBINED AGENTS; SUMMARY OF THE TEAM 8

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Ladies and Gentlemen !

During these days we have learned about various studies on the combined effects of several environmental factors. We have heard about many sophisticated studies on functional changes induced by noise together with whole body vibrations, hand-arm vibrations, chemical noxies such as carbon monoxide, toluene or tobacco smoke while subjects are doing mentally or physically loading tasks at different lighting and thermal conditions. A major part of the reported findings characterize acute or temporary changes in hearing thresholds, subjective responses and/or thermal regulation during or after multifactorial exposure conditions. Unfortunately, we still lack real long-term studies concerning these issues. In any case all the results demonstrated here show that the complex interactions between and combined effects of various environmental factors, including noise, pose real challenges to us. In general, factors in combinations, combined actions of the factors and combined effects form a richest source for future research initiatives.

Yet, the evaluation of the effects in combinations and realization of the studies concerned is by no means an easy task.

Even though a marked positive progress has taken place in this field of studies since the days of Stockholm Conference in 1988 or the days of Turine Conference in 1984 when the team was founded and even though the first consensus has been reached regarding the terminology and concepts for two-agent combined actions, a consistent body of terms must be evaluated soon and a consensus must be achieved about the proper use of terms as well as methods. To prevent a false use of various terms and methods for complex studies we have to join our efforts and face this problematic issue immediately and on a continuous basis; I must say that even during this meeting, in a couple of cases, concepts, descriptive terms and experimental settings reported here have been used in a way furthering confusion rather than clarity and understanding.

In mapping out other urgent and important scientific tasks in our field of combined agents we should try to initiate both national and international investigations that clarify effects of dissimilar factors such as mixtures of physical and chemical agents, mixtures of physical and mentally loading factors, unusual or exceptional exposure profiles including shift-and night-work. Furthermore, we must as soon as possible evaluate the daily total exposures of subjects, i.e. the combined effects of work time and leisure time exposures as well as changes in annoyances induced not only by different noises but by other

environmental factors such as odors and vibrations. When looking into the future neither the importance of applied studies nor the importance of developmental and consulting work should be forgotten. In this connection I would like to appeal to you again and repeat my earlier statement that people in small firms are a grateful public and they really need our wise advice. All kinds of noises as well as other environmental hazards form serious exposure combinations in the very smallest companies.

In order to solve the listed problems, at least partly, and to initiate the desired activities in our field, The Sixth Conference on Combined Effects of Environmental Factors (ICCEF 94) will be held next year,on September 25-29, in Toyama City, Japan. Connected to this conference, our new chairman Professor Kazuo Saito together with Doctor Andrew Smith, the new chairman of Team 4 and The International Society of Complex Environmental Studies, will organize a special ICBEN Day that will focus on work performances and combined agents. The scientific material of this event will be published in the periodical Archives of Complex Environmental Studies.

Ladies and Gentlemen

On behalf of the ICBEN Team number 8 and The International Society of Complex Environmental Studies, I welcome you all to this forthcoming interesting meeting next year and to contribute your essential input to our challenging endeavour. Thank you very much.

Bruit et agents combinés
Résumé de la session 8

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Durant ces journées, nous avons pris connaissance des différentes études portant sur les effets combinés de plusieurs facteurs environnementaux. Nous avons écouté les présentations de beaucoup d'études sophistiquées sur les changements fonctionnels entraînés par le bruit, conjointement aux vibrations du corps entier, aux vibrations mains /bras, des toxiques chimiques tels que le monoxide de carbone, le toluène ou la fumée du tabac pendant que les sujets exécutent des tâches mentales ou physiques dans différentes conditions de lumière et de chaleur.

Une grande partie des résultats rapportés caractérise des changements aigüs ou temporaires dans le seuil d'audition, les réponses subjectives et/ou les régulations thermiques durant ou après des conditions de travail multifactorielles.

Malheureusement, nous manquons encore de véritables études à long terme concernant ces questions.

Dans tous les cas, les résultats présentés ici montrent que les interactions complexes des effets combinés des facteurs variables de l'environnement comprenant le bruit nous proposent de véritables challenges. En général, les facteurs combinés, les actions combinées des facteurs et les effets combinés forment la source la plus riche pour des initiatives de recherches futures. Néanmoins, l'évaluation des effets combinés et la réalisation des études concernées n'est en aucun cas une tâche facile.

Même si un progrès significatif a été établi dans ce domaine d'études depuis les journées de la conférence de Stockholm en 1988 ou les journées de Turin en 1984 lorsque l'équipe a été créée, même si le premier consensus a été atteint au regard des terminologies et des concepts pour l'action de deux agents combinés, un ensemble énorme de termes doit maintenant être évalué et un consensus doit être trouvé sur l'utilisation propre des termes aussi bien que des méthodes. Pour prévenir une mauvaise utilisation des termes et des méthodes variés pour des études complexes, nous avons joint nos efforts et fait face à cette question immédiatement et sur une base constante. Je dois dire que même pendant cette réunion, dans un bon nombre de cas, des concepts, des termes descriptifs et des situations expérimentales ont été utilisées dans le but de plus de clarté et de compréhension.

En dressant d'autres tâches scientifiques urgentes et importantes dans notre domaine des agents combinés, nous devrons initier des investigations nationales et internationales conjointes qui clarifieront les effets des facteurs dissimilaires comme le mélange d'agents chimiques et physiques, le mélange des facteurs lourds physiques et mentaux, les inhabituelles ou exceptionnelles expositions incluant le travail de nuit et par équipes. Mieux encore, nous devons aussitôt que possible évaluer l'exposition journalière totale des sujets par exemple, les effets combinés de l'exposition durant les temps de travail et de loisirs aussi bien que les changements de la gène induite non seulement par différents bruits mais aussi par d'autres facteurs environnementaux tels que les odeurs et les vibrations. Lorsqu'on regarde vers le futur ni l'importance des recherches appliquées ni l'importance du travail d'exploitation et de consultation ne doit être oublié. Dans cette optique, je voudrais faire appel de nouveau à vous et répéter que les personnels des petites entreprises sont une population intéressante et qu'ils ont véritablement besoin de notre avis prudent. Toutes les sortes de bruit aussi bien que les autres risques environnementaux forment des combinaisons sérieuses d'exposition dans de très petites compagnies.

Dans le but de résoudre les problèmes listés, finalement partiellement, et pour initier les activités désirées dans notre domaine, la sixième conférence sur les effets combinés des facteurs environnementaux (ICCEF94) se tiendra l'année prochaine, du 25 au 29 septembre à Toyama City au Japon. Parallèlement à cette conférence, notre nouveau président Kazuo Saito avec le docteur Andrew Smith, le nouveau président de l'équipe 4 et la société internationale des études complexes environnementales organiseront une journée spéciale de l'ICBEN qui sera centrée sur les performances au travail et les agents combinés. Le contenu scientifique de cet évenement sera publié dans les Archives des études complexes environnementales.

NOISE REGULATIONS AND STANDARDS: PROGRESS, EXPERIENCES, AND CHALLENGES

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ABSTRACT

In adding a ninth team on "Regulation and Standards" to its eight scientific teams, the international Commission on the Biological Effects of Noise had several goals in mind: the exchange of information on regulatory approaches taken internationally, by various countries and in their local subdivisions; the reporting of successes and problems; and, perhaps above all, how the scientific community could best assist the rule and decision process. The potential health effects of noise on health and welfare are so manifold and the exposure conditions over a lifetime of such complex variety, that research continuously derives, proposes, and tests new criteria and dose-response relationships. These proposed changes and additions and their premature discussion outside the technical community can be a detriment to efficient regulation, enforcement, prospective planning, and public support. Review of the approaches taken over the last two decades appears to demonstrate that the combination of control of environmental exposures, occupational exposures and product noise emissions can be effective in limiting public exposure to desired levels - if consequently applied and enforced. In the use of available criteria, the clear distinction between three purposes is important: environmental impact assessment, land-use planning and use of dose-response health effects criteria. Unfortunately, frequently the differences between these three have been neglected. Scientific investigations, while separating these different purposes of regulations, should try to test the effectiveness of the simplest, most practical and yet protective approaches. Although few real-life noise exposure data on large populations exist, available evidence suggests that uncontrolled, mostly voluntary leisure time exposures make regulatory approaches not as effective as theoretically expected. In public education, product standardization, and legal noise control, the collaboration and continuing input from the scientific community are essential. To make this input coordinated and technically optimized should be the goal of the ICBEN Team on Regulations and Standards.

Introduction

The international congresses on Noise as a Public Health Problem. held in 5 year intervals by the International Commission on the Biological Effects of Noise (ICBEN), have assisted the development and exchange of information on the various ways noise can interfere with human activities and well being. Because of the complexity, variability and interaction of the various effects, any separation of these effects in occupational versus environmental effects, or into the eight scientific teams we have in ICBEN, is somewhat arbitrary. For certain environments such as workplaces, auditoria, schools, the various functions of rooms in residential homes, etc.. the selection of one type of criterion to avoid undesirable interference by the intruding noises is obvious. However, to select criteria to protect the health and welfare of the individuals moving freely and frequently between these spaces over days, weeks and a lifetime to account for differences in individual susceptibility, preference and lifestyle has been the subject of many studies, discussions and approaches. Efforts to define and control noise interference encompass a whole hierarchy of guidelines. regulations. laws and standards as illustrated in Fig 1. To enable this complex system to work, interact and be effective it is important that it uses the same definitions of public health and individual health, the same criteria -i.e. the same yardstick not necessarily the same limiting values - and the same measuring methods. To assist in the development and discussion of unified approaches to these problems the ICBEN added the ninth team on regulations and standards to its eight scientific teams. This team is not to develop regulations and standards but to propose how the scientific results could best be condensed in valid and effective - and in many cases unavoidably simplified - criteria for regulatory actions. *So I see as the primary goal of* the team how the scientific community can best assist the rule making and decision process.

Noise Abatement Policies - Review

In the last 25 years most governments adopted policies to protect the environment and improve the quality of life. The noise abatement policies and goals adopted were, in general, well conceived but the limited coordination between the various approaches listed in Fig 1 and the lack of enforcement of measures make it unknown how much objective improvement in the noise environment of people was really achieved. Perhaps in industrialized countries noise abatement efforts might have been able to prevent or slow down any further increase in noise levels shown to grow otherwise unavoidably with increase in population density, urbanization and industrialization unless noise conscious planning procedures are adhered to. At an OECD conference on Noise Abatement Policies in 1980, the approaches (listed in Fig 2) were reported on, discussed and recommended for adoption (1). Although priorities between the various approaches are hard to assign and probably have to be shifted from time to time depending on the situation, only a program well coordinated between the various

approaches and monitored as to its effectiveness can lead to success. Some of the efforts listed, such as the state of the noise environment, need research efforts monitoring the average noise environment every decade, others, such as the impact of noise on health, need continuing research and periodic assessment every five years of criteria and limit values used as we do it at the present conference. Changes in technology and economics might justify changes in metrics and consequently in criteria (e.g. dBA vs PNL?). Most of the other approaches need study, assessment or education. Above all one needs an assessment of the overall effectiveness of the mountain of regulatory actions, not only with respect to their individual cost effectiveness but primarily with respect to their impact in reducing the daily noise exposure of the population.

The policies implemented over the last 25 years in most countries were probably most effective in two areas: regulating occupational noise exposure and hearing conservation programs on the one side and regulating the primary environmental noise sources through civilian aircraft type certification on the other side (2). Unfortunately, with respect to the individuals, noise exposure control of the occupational exposure is frequently contrasted by an increase in non-occupational leisure time exposure-be it voluntarily or not. Similarly the tremendous advance in jet aircraft noise reduction is not fully appreciated by the population due to the increased air traffic and indequate airport planning. Noise as a public health problem outside the workplace became primarily critical through the increase in aircraft and other transportation noises. Their short-term and long-term impact through various types of activity interruption such as speech interference, sleep disruption, and annoyance and their potential stress effects and clinical manifestation is in general, on the average, satisfactorily measured by the long-term equivalent sound level (L_{eq}) or the day-night average sound level (DNL) (3)(4)(5). In spite of some criticism and the obvious possibility to refine the assessment in specific situations it is and should be the basis for currently describing, assessing and controlling the impact of environmental noise and transportation noise. The relationship between the percentage of people reporting in social surveys to be highly annoyed by the day-night average sound environment has served as a valuable nominal predictor of the overall impact of living in noisy environments. A recent update of this dose-response relationship, the so called Schultz curve, by tripling the size of the data base by adding 11 social surveys published since 1978, confirmed the confidence in this relationship by hardly changing its function (Fig 3)(6)(7). (However, at higher DNL values annoyance from traffic and railway noise is not quite as high as the values predicted for aircraft noise(Fig 4)(7). In acknowledging these results a recent Federal Interagency Committee on Noise (FICON) in the US confirmed DNL as the principal environmental noise metric and recommends the updated "Schultz Curve" as the best available source of information to predict community response to transportation noises (8):

$\%$ Highly annoyed$=100/(1+\mathrm{Exp}(11.30-.141\ L_{dn}))$

For the assessment of specific disturbances other measures are recommended. For the mean percentage of a population awakened by a transportation noise event, the sound exposure level (SEL) is proposed with the following relationship as interim criteria (7)(8):

$\%$ Awakenings$=7.079\mathrm{x}10^{6}\ \mathrm{SEL}^{3.496}$ (Indoor)

In general it is comforting to see that the metrics and criteria proposed in the US EPA Levels document two decades ago withstood the test of time with respect to general as well as specific health effects and that it is certainly not the lack of technical and scientific knowledge which delayed the application of noise abatement policies.

Unfortunately some confusion was introduced into the regulatory process - at least in the US - by using the same metrics but with different limiting criteria or levels for different purposes and to satisfy different legal purposes. One has to distinguish between; (a) the environmental impact of noise, which exists to some degree from any change or increase of the noise environment even at very low levels with or without human populations present and only wildlife around; (b)the impact on public health and welfare; (c)the potential impact on individuals health and, (d) the impact of noise on anticipated land use. Many regulatory actions must start at existing realities, where in many industrialized countries over 15 percent of the population live in daily noise environments with levels regarded as unacceptable (L_{dn}>65dB) and over half of the population lives in environments above the level of comfort (L_{dn}>55dB). The long range desirable goals with respect to our noise environment are not the same as the realistic shorter-range solutions subject to many other competing interests, economic, social, as well as political. This does not mean that our noise-abatement efforts are futile. Looking at the policies advocated in Fig 2 it is obvious that most actions have inherently a long time constant to become effective and even 10 years might be too short a time span to notice progress. We should not become impatient. However, as mentioned above, we should monitor the state of our noise climate. Some of this work, I am afraid, is missing.

International Cooperation/Harmonization - EEC/ISO

The exchange of scientific information and product noise certification requires international standardization of measurement instruments, measuring methods, procedures and of all metrics to be applied and to be reported. The important work in this area of the International Standards Organization (ISO) received new impetus and support from the European Economic Community (EEC), when by the European Act of 1986 it decided to accelerate the process of harmonization of regulations by introducing the principle of qualified majority decision. Legislative harmonization is limited to the adoption of "essential safety requirements", with which products must conform; the task of providing the technical specifications for producing and placing these products on the market is entrusted to the European

standards have the status of voluntary standards. (See Fig 5) The general EEC directives to eliminate technical barriers to trade address safety of persons and harmonization of provisions to ensure free movement of goods. Specific directives related to acoustics are listed in Fig 5 and the required technical standards were energetically attacked by the CEN Technical Committee 211 "Acoustics". At its first meeting in 1990, the committee decided to adopt whenever possible existing International Standards and when no suitable International Standards exist to ask the relevant ISO or IEC committee to undertake the development of the required new standard. This decision was the start of a very effective and productive collaboration between European and International Standards Activities energizing activities of ISO/TC43 "Acoustics" and its subcommittee SCI "Noise" meeting European requirements and target dates while considerably accelerating ISO activities and procedures. The acoustical technical community took these important steps even before ISO and CEN officially streamlined their general policy of cooperation in their so-called "Vienna Agreement", which among other steps to accelerate the standardization process permits parallel voting in both organizations on new documents circulated to ISO member bodies. The present activities of ISO/TC43 "Acoustics" and of ISO/TC43/SCI "Noise" are summarized in Fig 6 and 7. Work items related to worker safety and machinery noise emission prevail. After final adoption of ISO 1999 "Acoustics - Determination of occupational noise exposure and estimation of noise -induced hearing impairment" in 1990 (9), TC43 is now working on a standard allowing evaluation of the effectiveness of hearing conservation programs. Of the 21 working groups of TC43/SCI, some of which have more than 3 work items i.e. standards under consideration, it is hard to *identify projects with the highest priority. 58 ISO standards issued by SCI* exist, 63 are in a state of revision or preparation (Fig 7). However it is worth while to mention that a new type of ISO document, "Guidelines" for the design of low-noise machinery and of low-noise workplaces, is also in the work schedule.

Summary

This brief review of the present status of noise regulations and standards tries to emphasize a few points addressed to the scientific community on how it could and should actively participate in the regulating and standardization process.

In spite of a well conceived hierarchy of regulations and standards, we have very little evidence how well the overall system works. Unfortunately the few available data suggest that the average urban population not exposed to industrial noise exposes itself to L_{eq} (24) values of 70 dB and above; children are exposed to still higher levels (10)(11). These frequently voluntarily accepted exposures are higher than the environmental levels we try to achieve with our regulatory control system.

More studies are needed on the average long-term exposure of individuals during their 24 hour day. Is this integrated individual exposure decreasing as a result of our regulatory efforts? Are our environmental noise levels decreasing? Are the high voluntary, leisure time exposures the result of lack of education? Real-life exposure studies of individuals and of the various environments are needed and should be repeated at 5 or 10 year intervals to check the overall effectiveness of regulatory programs.

The participation of the scientific community in the technical standardization process is highly desirable. Although this work requires patience and consideration of other points of view and approaches, it is technically highly rewarding to the individual and benefits the overall noise abatement goal.

In general, the metrics and dose-response relationships advanced two decades ago as the basis of noise abatement policies have been confirmed by newer studies. Although reassessment and some corrections might be indicated from time to time such adjustment of metrics or criteria should not be allowed to impede the successful continuation of noise abatement efforts. It is clearly up to the scientific community to respond to these challenges in a responsible and timely manner.

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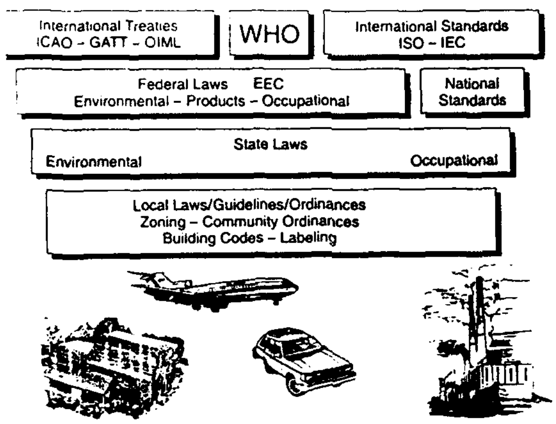

Fig.1 NOISE REGULATIONS AND STANDARDS

- STATE OF THE NOISE ENVIRONMENT
- IMPACT OF NOISE
- REGULATING FOR NOISE ABATEMANT
- LOCAL ACTIONS - PILOT "QUIET TOWNS"
- NOISE CHARGES
- COMPENSATION FOR DAMAGE DUE TO NOISE
- EDUCATION AND INFORMATION
- COSTS OF NOISE ABATEMENT
- NOISE ABATEMENT IN THE CONTEXT OF ENERGY CONSERVATION
- INTERNATIONAL COOPERATION AND HARMONIZATION
- WHAT IS NEEDED: ASSESSMENT OF OVERALL EFFECTIVENESS

Fig.2 Noise Abatement Policies

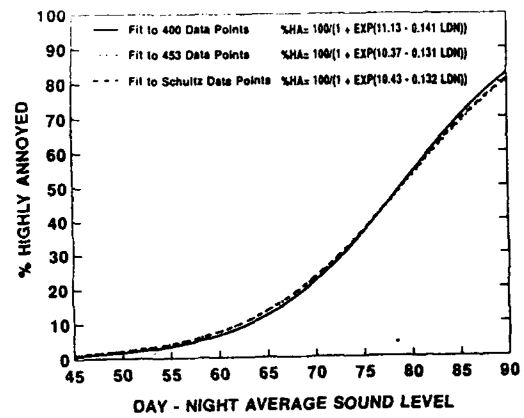

Fig.3 Logistic Fits to Schultz Data and to 400 and 453 Data Points from Fidell et al. (6) (7) (8)

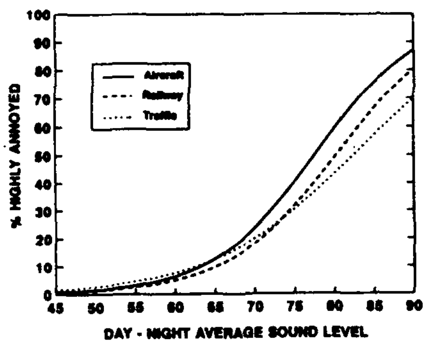

Fig.4 Comparison of % Highly Annoyed vs. Ldn from Aircraft, Road Traffic and Railway Noise, Based on Data from Fidell et al. (6) (7)

- DIRECTIVES TO: ENSURE SAFETY OF PERSONS, DOMESTIC ANIMALS AND GOODS

  HARMONIZE PROVISIONS TO ENSURE FREE MOVEMENTS OF GOODS
- TECHNICAL SPECIFICATIONS/HARONIZED STANDARDS ENTRUSTED TO CEN AND CENELEC
- GLOBAL APPROACH TO CERTIFICATION AND TESTING
- EEC DIRECTIVES RELATED TO ACOUSTICS:
  - PROTECTION AGAINST NOISE AT WORK\
  - CONSTRUCTION PRODUCTS: OCCUPANTS PROTECTED AGAINST LEVELS AFFECTING HEALTH, SLEEP, REST, WORK
  - MACHINERY: *NOISE EMISSION TO BE REDUCED* TO LOWEST LEVEL.
    INFORMATION WHERE dBA > 70 dB
    dBC > 130 dB
    LEQ > 85 dB
  - PERSONAL PROTECTIVE EQUIPMENT
- MAIN RESPONSIBILITY: CEN/TC 211 "ACOUSTICS"
  , CEN ADOPTS ISO STANDARDS OR ASKS ISO OR IEC TO UNDER TAKE PREPARATION
- CLOSE COOPERATION BETWEEN ISO/IEC AND CEN. *PARALLEL VOTING*

Fig.5 European Economic Community (EEC)

- 25 PARTICIPATING COUNTRIES
- 26 OBSERVING COUNTRIES
- 5 WORKING GROUPS: THRESHOLD OF HEARING

  AUDIOMETRY

  EFFECTIVENESS OF HEARING CONSERVATION PROGRAMS

  REAL EAR CHARACTERISTICS OF HEARING AIDS
- 14 ISO STANDARDS

SUBCOMMITTEE SC1: NOISE
SUBCOMMITTEE SC2: BUILDING ACOUSTICS

Fig.6 ISO/TC43 "ACOUSTICS"

- 25 PARTICIPATING COUNTRIES
- 12 OBSERVERING COUNTRIES
- LIAISON WITH 31 OTHER ISO/IEC TECHNICAL COMMITTEES

- ROTATING ELECTRICAL MACHINES
- COMPUTERS AND BUSINESS EQUIPMENT
- HEARING PROTECTORS
- MEASUREMENT OF SOUND INTENSITY
- TEST TRACKS FOR ROAD VEHICLE NOISE
- ACOUSTICAL PROPERTIES OF RESILIENT ELEMENTS
- NOISE INSIDE AIRCRAFT
- TRAFFIC NOISE ON DIFFERENT ROAD SURFACES
- ABSORPTION OF ROAD SURFACES
- PAVEMENT SURFACE MACROTEXTURE
- SOUND EMISSION OF STATIONARY SIRENS
- GUIDELINES FOR THE DESIGN OF LOW-NOISE MACHINERY AND EQUIPMENT
- GUIDELINES FOR THE DESIGN OF LOW-NOISE WORKPLACES
- MACHINES AS SOURCES OF STRUCTURE-BORN SOUND
- NOISE ON BROAD VESSELS
- SOUND PROPAGATION OUTDOORS
- ISOLATED BRUSTS OF SOUND ENERGY
- SOUND POWER LEVELS OF NOISE BARRIERS
- INSERTION LOSS OF NOISE BARRIERS
- NOISE INSIDE AIRCRAFT
- NOISE ATTENUATION DEVICES
- IMPULSE SOUND PROPAGATION

- *MANY WORKING GROUPS HAVE SEVERAL WORK TERMS/* PROPOSED STANDARDS
- 63 DOCUMENTS IN PREPARATION
- 58 ISO STANDARDS BY SCI

Fig.7 ISO/TC43/SCI "NOISE"

Standards for industrial environmental noise exposure : current UK research

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ABSTRACT

Both of the authors are members of the British Standards Institution (BSI) technical committee responsible for standards for the assessment of industrial noise as it affects people living near sources of such noise. The relevant standard in the UK is BS 4142 : 1990 "Method of rating industrial noise affecting mixed residential and industrial areas". A new edition of this standard was issued in 1990 after an extensive revision of the original document, first published in 1967 (1). Work is now in progress on a further short-term revision, due for publication at the end of 1993, and on a longer term revision over the next 3 years. As part of the strategic approach to this more extensive revision, the committee is taking account of a number of related research projects currently in progress in the UK. This paper identifies these projects, summarises them and considers how the research results will be utilised in standardisation.

1. Introduction

In the United Kingdom, the responsibility for development of standards for noise measurement and assessment falls to the British Standards Institution's "Environment and Pollution Standards Committee EPC/1 - Acoustics". Below this are a number of Technical Sub-Committees dealing with specific topics such as aircraft noise, traffic noise etc. The environmental aspects of industrial noise are the responsibility of EPC 1/3 "Industrial and Residential Noise", of which the first author has been the Chairman for the past 7 years. The standard used for the assessment of industrial noise in the UK is BS 4142 "Method of rating industrial noise affecting mixed residential and industrial areas". Essentially this gives a method of determining a noise level, correcting it to take account of the character of the noise, and comparing the rating level with the background in order to assess whether the noise is likely to give rise to complaints.
The standard was first published in 1967. A formal decision to begin revising BS 4142 was made in 1984 when ISO 1996 Part 1 was published. A draft for Public Comment was issued in 1988 and the revision was finally completed at the end of 1990. In particular the method of quantifying the noise was updated to use the

Equivalent Continuous Sound Pressure Level, L_{Aeq}, in line with ISO 1996. Not surprisingly, given the long gestation period of the 1990 edition, by the time it was completed, pressure for further revision was growing. The UK Department of the Environment formed a Noise Review Working Party in 1990 to consider many aspects of noise control, taking as its base the 1974 Control of Pollution Act. Amongst the recommendations of the Working Party in the so-called "Batho Report" (2), were the following:

> *"There should be a more extensive revision of BS 4142 than has been possible in the current review. A future Standard should take account of peaks of noise and of noisy events of short duration, particularly at night"*
>
> *"There should be further research into community response to various types of industrial noise"*

In fact, even before the 1990 edition was published, new research was underway, such as the CEC Joint Project on Impulse Noise (3). At the end of 1992 the BSI Committee formally began the process of further revision by forming a Working Group to produce a quick revision within 12 months and also agreeing to monitor various related research projects over the 3 year period to 1996 in order to see how results could be incorporated into a longer term revision. An area of particular interest was the question of "penalties" or corrections to be added to L_{Aeq} for the presence of tonal and impulsive characteristics.
Let us now review some of this current research.

2. Research in progress

The key projects in the UK are listed in the table below, and then summarised in subsequent sections.

Contractor	Customer	Topic	Completion
ISVR	DoEnv	Quantification of tonal noise	December 1992
NPL	DoEnv	Subjective and objective assessment of industrial noise	December 1993
W S Atkins	DoEnv	Pilot study of disturbance due to industrial noise	December 1993
W S Atkins	DTI	Standards for industrial environmental noise exposure	December 1995

DoEnv = U K Department of the Environment
DTI = U K Department of Trade and Industry
ISVR = Institute of Sound and Vibration Research
NPL = National Physical Laboratory

2.1 Quantification of tonal noise

This project has been underway since 1988 at the Institute of Sound and Vibration Research in the University of Southampton. The work has included:

* A survey of practice and opinion of local authorities
* Preliminary experiments on detectability, tonality and annoyance matching
* Experiments on annoyance rating of discrete tones in broadband noise
* Development of a rating method for a tonal penalty
* Implementation of the method in a hardware demonstrator using DSP techniques

An excellent overview of the project was provided by Professor Robinson in his paper at the Euronoise '92 Conference (4), and his paper gives references to 5 other ISVR publications arising from this work.

2.2 Subjective and objective assessment of industrial noise

This 3-year project at the National Physical Laboratory began in December 1990 and is funded by the Department of the Environment (DoEnv). It is in three parts.

a) Laboratory experiments are being conducted on the judged annoyance of specific types of industrial noise to explore the effect of impulsiveness and tonality on subjective annoyance. The emphasis is on the use of actual recordings from existing sites, rather than simulations, and particular attention is being given to cases of combined tonal and impulsive noise. This work has been described in a paper by Porter and Berry at Euronoise '92 (5), and more recent experimental work is the subject of a further paper at this Conference (6).

The noises used in the experiments are to be analysed by a number of objective methods including those developed at NPL for impulsive noise e.g. the Increment descriptor (7), and those arising from the ISVR studies of tonal noise. Relationships between subjective and objective assessments will be investigated to assist the optimisation of rating methods.

b) To enable a systematic evaluation of the application of the 1990 revision of BS 4142, and hence provide information to assist future development, a special data-sheet has been designed and supplied to 140 volunteer users - mainly Environmental Health Officers and noise consultants - who have documented case studies of industrial noise complaints and indicated how the assessment method contained in the standard is working in practice (8).

c) A review has been conducted of various national practices on the assessment of industrial noise across 20 countries, using a questionnaire sent to national laboratories, standards institutions and Environment Ministries. In particular

information is being gathered on how different countries have implemented ISO 1996. Useful information has been obtained on objective rating methods used and on the treatment of noises with particular characteristics such as tonal and impulsive noise. This study was described at Euronoise '92 (9), and a full NPL report is to be published by September 1993.

2.3 Pilot study of disturbance due to industrial noise

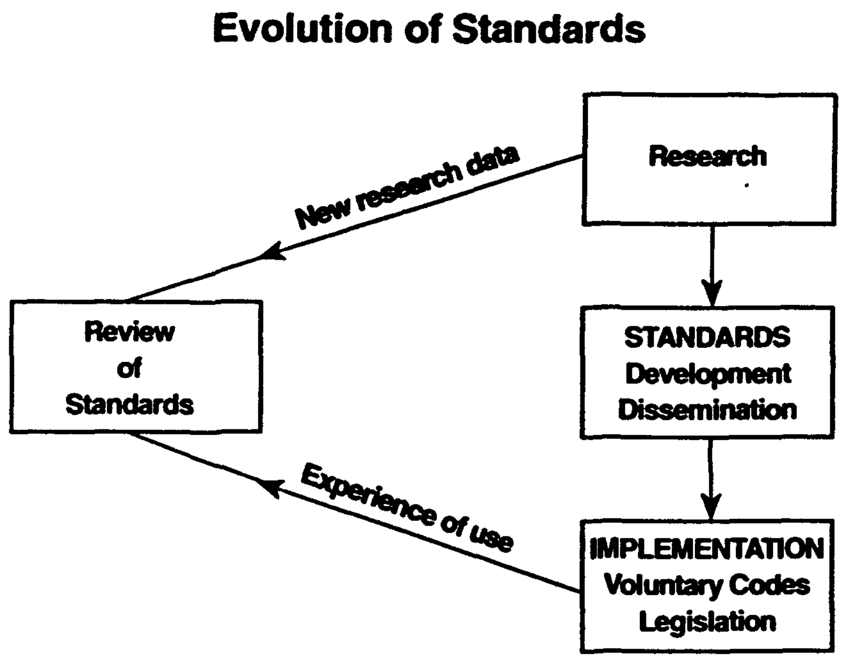
This study by W S Atkins Noise and Vibration, under contract to the Department of the Environment, has been underway for a year. It takes as its starting point the fact that very few social surveys have been conducted on reactions to industrial noise, compared to the large number on aircraft and traffic noise. As a pre-cursor to any major social survey exercise, this pilot study aims to formulate a questionnaire survey and a noise measurement survey strategy, and to test the strategy on six sites, some of which will involve noise of tonal or impulsive character.

2.4 Standards for industrial environmental noise exposure

This study is of interest not only from the scientific point of view, but also as an example of a new system of research funding in the Department of Trade and Industry (DTI), which is the principal "customer" Department for the work of the National Physical Laboratory, which maintains the National Measurement System in the UK. Work on the topic of industrial environmental noise exposure was designed into the planned NPL 3 year programme on acoustic metrology for 1992 to 1995. To an extent this was seen as an extension of the work described in Section 2.2, and also part of the first author's strategic plan for BS 4142. It is now DTI policy to identify NPL work which is suitable for competitive tendering. The planned project on industrial noise was designated as suitable. NPL was closely involved in the drawing up of the specification for the tender, and then had to prepare a detailed project proposal to compete against a number of organisations, from both the public and private sectors, in order to secure funding for the project. In the end the contract was awarded to W S Atkins, but NPL has the role of monitoring progress and managing the project as part of the overall Acoustic Metrology Programme. The specification calls for the development of new measurement standards comprising of a comprehensive rating procedure for environmental noise of industrial origin, taking into account subjective reaction to the significant acoustic features of the noise. The project began in January 1993 but at the time of the Conference (June 1993), there is little progress to report.

3. Evolution of Standards

The development of standards is a continuous process of implementation, review and revision. Figure 1 gives a simplified graphic description of this process. Research, of the kind described in this paper, forms an integral part of the process.



With the specific aim of improving standards for industrial environmental noise, the British Standards Institution Technical Sub-Committee EPC 1/3 will be monitoring progress on the projects described here and will also be taking into account other work in the UK and elsewhere. The possibility of a new ISO Working Group on impulse corrections as used in ISO 1996 provides a further means of continuing the evolutionary process.

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NOISE AND THE ART OF MAINTENANCE

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Summary

Defining noise standards is a difficult task. Luckily nowadays a wealth of scientific knowledge is available to help policy makers in making decisions.

Once the standards are agreed upon, they will have to be implemented in society, which in most countries (but not all) goes by way of some form of regulation. This may be a formal law, or regulations of lower order.

These regulations will have to take into account three "threats" to the noise environment:

(1) New noise sources
(2) New noise sensitive elements near an existing source
(3) Changes in existing more or less noisy environments

This paper deals largely with problem number three as its importance in maintaining a quality once agreed on one is often overlooked. This importance follows from data about the increase of noise sources.

This paper is about the way we may treat sudden or gradual increases in noise levels, from the point of view of noise regulation. It stresses the point that writing the noise standard on a piece of paper and hoping the best of it is usually not enough. Generally in noise regulation the following items will have to be covered:

(1) For what noise sensitive activities and on which decisions does the rules apply
(2) On which noise producing activities
(3) Material effects of noise standards.
(4) how to control noise standards over time

A short introduction on the first tree items is necessary before concentrating on item (4).

(1) Standards for noise sensitive activities

Most noise regulations focus on residential areas. Often a distinction is made between houses in suburban and urban areas, in the assumption that houses in urban areas already have high noise loads so somewhat more or less doesn't matter. This, however, is ethically an unsound point of view. From very simple reasoning it can be demonstrated that
Hospitals and schools are usually considered more sensitive to noise.

(2) Noise sources.

Noise sources differ widely in many ways. Relevant differences are:

- Noise characteristics.
  The frequency-time pattern from a railway is different from that from a motorway. In the first instance high noise events separated by quiet periods, in the second case there are may vents with no quiet at all. This will influence the effect. An ideal noise descriptor gives the same number for equally annoying noises. Scientist are looking for this Philosophers stone of noise abatement for many years and probably will do so for some time to come, but for the moment we will have to live with descriptors we have, and make adjustment per noise source.
- Control.
  Some noise sources are easier to control then others. Aircraft movements are individually monitored on a routine-base by air-control authorities. On the opposite end, motorbikes are individually operated, monitored only by chance and only interfered with in extreme cases. Other noise sources have other peculiarities, which influence the ways they can be controlled.

These considerations not only leads to different standards, but also to different regulatory systems, in which the different characteristics of the noisy source are taken care off.

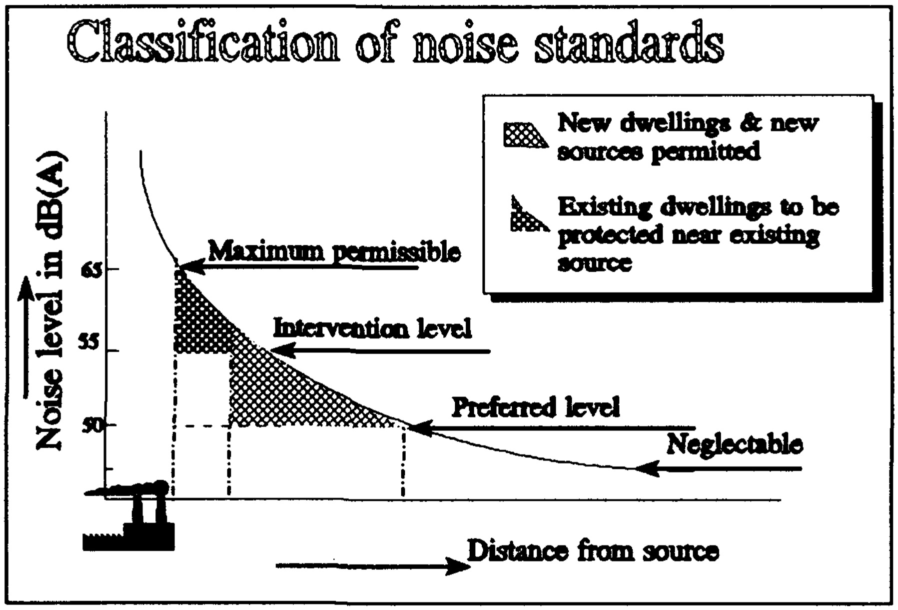
(3) Material effects of standards.

In noise immission regulation (that is, setting standards for outside noise as opposed to setting noise standards for the emission at the source) the following definitions apply:

I. The no-adverse effect level;
II. Preferred value: the environmentally safe value, which may in some cases be slightly over the no adverse effect level;

III. Maximum acceptable level: above this value the risk of health damage becomes unacceptable
IV. Intervention level: Situations which exceed this level, may have to be corrected.

At least II and III will need to be included in a regulation, and IV is highly recommended.
The distinction between I and II may seem vague, but one can imagine a level where no annoyance at all or no sleep disturbance at all can be demonstrated. This no-effect-level can only be reached at very low levels indeed. For the preferred level one takes into consideration that a small percentage of the population is extremely sensitive, and can only be protected outside normal life. So for this level some (minor) effect is tolerated.
In the next figure the relationships between the limiting values are given. The numbers on the y-axis are not chosen by chance; they reflect the actual values for the Dutch Noise Abatement Act, section industrial noise.



The figures for the other noise sources differ slightly, as may be seen from the next table:

Table 1. Review legal Limits as stated by the Noise Abatement Act

Limits*)in dB(A) (+..)=temporary correction anticipating less noisy equipment (-..)=penalty to be subtracted					
		Maximum allowable if conditions are met			
Source	Preferred	"New"	"Existing"	Intervention thresholds	INSIDE
Road traffic local	50 (+5) dB(A)	65 (+5) dB(A)	70 (+5) dB(A)	55 (+5) dB(A)	35dB(A)
Road traffic Motorways	50 (+3) dB(A)	55 à 60 (+3) dB(A)	70 (+3) dB(A)	55 (+3) dB(A)	35 dB(A)
industry	50 dB(A)	55 à 60 dB(A)	55 à 65 dB(A)	55 dB(A)	35 dB(A)
impulse noise	50 (-5) dB(A)	55 à 60 dB(A) (-5)	55 à 65 dB(A) (-5)		35 dB(A)
railway noise	57 (+3) dB(A)	70(+3) dB(A)	70 (+3) dB(A)	65 dB(A)	37 dB(A)

*) *Values are calculated from separate day (7.00-19.00), evening (19.00-23.00) and night (23.00-7.00) levels. To the evening level 5 dB(A) is added, and to the night level 10 dB(A). The highest of the three is the legal value. This amounts more or less to the standard Ldn procedure with a night penalty of 10.*

The differences arise mainly from differences in annoyance as shown by scientific research. Other factors (like economic costs) come into play, especially when it comes to setting the maximum allowable levels.

Setting standards is not enough, something has to be done with them. Generally spoken you would like to avoid any noise loads over your preferred level. Looking around, one realizes that this is not always possible.

The first step is to make sure that the actors in the process (those who produce noise, those who produce noise sensitive sites and those who may be responsible for bringing them together) first think about the consequences and then make their decisions.

The next step is to make sure that the preferred level will not be exceeded, for instance by demanding a noise screen.

If the cost of reducing the noise levels is to high, as a last resort the facades of the houses will have to be insulated.

(4) Control over time

Noise legislation came long after the first trains, motorcars and planes appeared. This means that when a noise abatement regulation comes into force, it will find itself facing a certain amount of noisy situations, part of which will be totally unacceptable according to the standards.

It is the competence of the authorities to clean up unacceptable noise loads as soon as possible. At the same time however, new unacceptable situations must be avoided, otherwise the cleaning up continues forever.

With the standards set, avoiding high noise loads when constructing new motorways, new

railways, or new residential areas is relatively easy. It may take some time to convince the road builders that there is something like an environment around their structures.
The example I started with is only one illustration of the problem of sudden or gradual changes in noise loads. Noise levels may change for a lot of reasons; in fact by as many reasons as there are input parameters in the calculation-method!
First some general principles:
(1) Stand-still: noise loads shouldn't increase!
(2) The polluter pays
(3) Application of best technical means to reduce noise

To show where these principles lead to in the context of the standards described in section 3, I take the example of the Dutch Decree on Railway Noise Annoyance.
This Decree came into force july, 1st, 1987. It defines the railways covered by the Decree on a map which is part of it. The map also indicates the noise zones along the railways. They vary from 100 meters to 500 meters (on both sides of the track).
The following activities are considered:
(1) constructing new railways
(2) making land use plans that foresee new noise sensitive activities within the noise zones
(3) changes with regard to a railway that may influence the noise immission.

The first two items are relatively straightforward. The actor has to do acoustic research within the zone to show that the preferred level -presently 60 dB(A), see table 1- is not exceeded. If it can be shown that higher levels are unavoidable (a set of criteria is provided) then the higher noise level has to be registered by the regional authorities. Higher levels then the maximum allowable level of 73 dB(A) cannot be registered. In registering the authority may impose restrictions on the way the activity is executed, for instance the orientation of a building-block,
So far so good, all new railways and all new residential areas as well as schools and hospitals and a few other odd noise sensitive activities or will satisfy the preferred level, or will be registered.

Changes with regard to a railway are defined as any change that may influence the noise immission. Following the -obligatory- calculation method, one comes to the following items:
- Changes in use of the railway: number of trains, type of trains, speed of trains;
- Changes in geometry: horizontal and vertical position of the track, number of tracks;
- Construction of the track

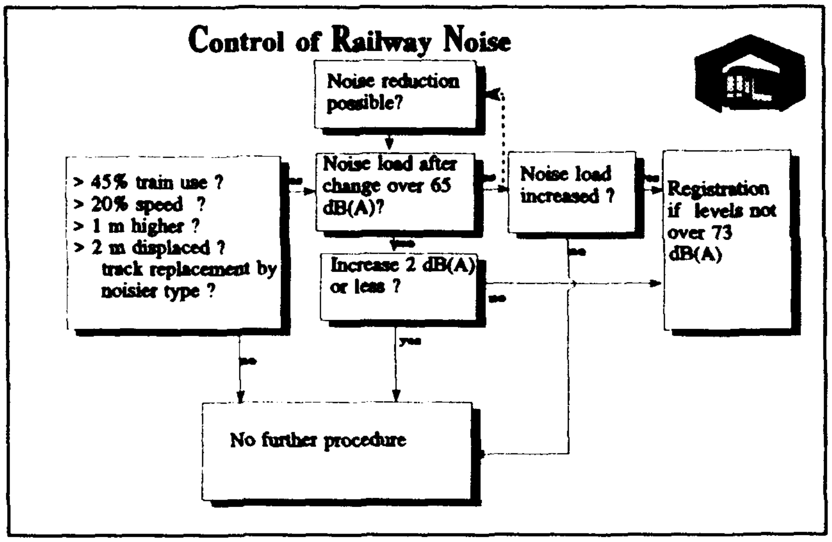
Two types of threshold values have been set to avoid too frequent interactions. First with respect to the railway:
- Speed: more then 20% increase in mean speed
- Use: more then 45% increase in number of train-units
- Horizontal displacement: more then 2 meters
- Vertical displacement: more then 1 meter.

Changes more then these threshold values cause the railway-operator to perform acoustic research. The outcome has to be viewed against the following threshold levels:

- If the resulting noise level on the facade is less then 65 dB(A) (the intervention level) then an increase of 2 dB(A) or less may be neglected.
- If the resulting noise level is higher, then any change leads to a proposal to decrease the

noise level.

The following scheme may help to identify the steps in the process.



Very important is the question what the starting point is to calculate the increases from. The Decree states that the difference is calculated between the noise load after the change has taken place and the registered level if there is one, or the 1987 level (the moment the Decree came into force) or the actual level if that is lower. This means that any not-registered increases (for instance by successive increases below the threshold-levels) will be covered the moment the procedure will have to be completed.
Controlling this all is made possible by an extensive database containing all the emission factors of the railway network. This includes the number of train-units per hour per category, speed per category, braking behavior, and details about track type. The computer-database is made available in detailed form to acoustic advisors and in a much more global format to the local authorities.

5 Discussion

Not always it is possible to control noise emission factors as is the case with railways. Road-authorities usually will observe that they have not the power to stop people using their roads, so they are not responsible if over the years more cars or trucks then predicted pollute the countryside. Although this holds true at first sight, this doesn't mean that nothing can be done about it. It seems obvious that the a road authority that makes a connection can and must be held responsible for the noise increase this might cause in adjacent streets. Nowadays traffic planning has become something more of a science then of an art, and traffic streams are predictable with high degrees of accuracy. So if in such a traffic plan an increase in noise load is forecasted, should then not the same procedure follow as for the railway network?
The same goes for the noise from airports, and there it should be easier still.
The bottomline is this.
If it is worthwhile to set noise standards and to spend money on reaching the standard, then it is certainly worthwhile to think about systems to maintain a once reached quality. Modern techniques of registration and calculation are available to help us.

INTERNATIONAL ASPECTS OF NOISE STANDARDS COMPARED TO OTHER ENVIRONMENT FACTORS

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Abstract:

At the United Nations Conference on Environment and Development in Rio de Janeiro 1992 noise control did not play a major role. This reflects the general situation in the international environmental discussion: priority is given to environmental issues of global relevance e.g. global warming, ozone depletion, deforestation, desertification, water pollution. Nevertheless noise has great relevance. This increasingly is recognised also on behalf of urban centers in the developing countries. The industrialised countries have a moral obligation to support developing countries upon request by transfering know-how acquired over the last few decades and by making available experience in developing technical, administrative and legal noise abatement strategies.

1992 was a particularly important year for the international environmental discussion: 20 years after the first world-wide environmental conference held in Stockholm in 1972 the United Nations Conference on Environment and Development - UNCED - took place in Rio de Janeiro in June last year. UNCED had dimensions which no other international conference has reached before: more than 30 000 people from all over the world,

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about 120 heads of states and governments, hundreds of high ranking politicians and officials, thousands of journalists attended the conference.

The Stockholm Conference focused environmental protection as an interest of global cooperation and had culminated in the establishment of a specialised agency for environmental issues in the UN system, the United Nations Environment Programme - UNEP -.

On the Rio-Conference's agenda was the definition of appropriate strategies and measures to stop the on-going degradation of the global environment and the agreement that all countries of the world have to use and develop the planets natural resources in an environmentally sound and sustainable manner. Environmental protection has to become an integral part of the economic and social development and an indispensable element of political thought and action.

This conceptual approach has found concrete expressions in 5 important documents of UNCED:

- two global conventions, the Conventions on Climate Change and on Biological Diversity containing legally binding commitments, were signed at Rio by not less than 154 states;

- the Rio-Declaration contains in 27 articles fundamental guidelines and principles for environment and development policy;

- the Declaration on forest principles defines the basis for management, conservation and sustainable development of all types of forests;

- with the Agenda 21 a comprehensive action programme with 40 chapters covering all areas of environment and development, adopted by the whole community of states.

Before the end of last year the UN General Assembly took decisions to support effectively a prompt start to implement UNCED. A high level UN-Commission on Sustainable Development with 53 member states was established in February with the mandate to monitor the implementation of UNCED's decisions. Its first substantive session in New York last month was attended by more than 40 ministers. I am convinced that a conciderable step has been done by UNCED and its follow-up in the last 12 month to realize a new global

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cooperation with the aim to save our planet and to ensure human dignity.

But - what about noise in this global environmental and development context?

Noise was not mentioned in the UN General Assembly's Resolution No. 44/228 of 22 March 1990 as being one of the issues of major concern to be addressed at UNCED. And indeed - noise control did not rank high on UNCED's agenda, a fact that reflects more the situation which is characteristic of the international environmental discussion generally. Noise is mentioned only a few times in the Agenda 21.

So e.g. under para. 6.41 of agenda 21 in the chapter dealing with "protection and promoting human health" we find the sentence, that nationally determined action programms should include also besides a lot of other issues to "develop criteria for maximum permitted safe noise exposure levels and (to) promote noise assessment and control". Elsewhere in the agenda 21 noise plays an even minor role.

The question arises whether such a posterior treatment of noise problems is factually justified and, if not, what could be done to ensure that due account will in future be taken of noise problems in the international environmental discussion.

We have to be aware that priority has been given and will be given throughout the world to environmental issues such as global warming, the ozone depletion, the contamination of our drinking water, increased deforestation, dersertification and degradation of vast areas of land, the loss of biological diversity and the threat posed by the transport of hazardous and toxic wastes and products. Although these issues touch on completely different spheres of life, they have one thing in common: they all refer to essential elements of our living environment being threatend by serious damage and have all acquired a transnational or even global scale: and once such damage has occured it cannot be repaired at all or only over a relatively long period.

Noise differs from these environmental issues in more than one respect. For instance,

- in most cases, the influence zone of noise is relatively limited,
- its effect ends as soon as the respective noise emission is stopped,
- the immission pathways of noise are largely predictable,
- irreparable damage is not likely occur expect for undividual exposed persons,
- mankind's basis of existence is not affected.

Of course, this does not imply that noise is irrelevant. This is substantiated by a study published 2 years ago (Berichte 9/91, Umweltbundesamt, Erich Schmidt Verlag, Berlin, p.230 ff.), which estimates the Federal Republic of Germany's annual costs accruing from noise at 26 to 28 billion D-Mark. Over the last few deca-

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des, considerable technical efforts have been made to reduce the number of jobs exposed to excessive noise. In the industrialised world, a wide variety of sophisticated measures has been taken to reduce the level of noise emitted by vehicles, aircraft and machines and to improve soundproofing within buildings. In the Federal Republic of Germany, further improvements have been achieved by various low cost measures - e.g. noise-conscious work flow planning, limiting the duration of workers' exposition to noise or using buildings, machines and equipment on building sites as noise barriers in developing countries most of them are not yet familiar with noise control. The major point of concern is to inform policy and decision-makers of the noise problems, the propagation of noise and its health impacts and to win their support for making due allowance to noise control in environmental policy, fully recognising the priority of other environmental concerns.

The developing countries have started to realise that noise is a quite important issue. Thus, for instance the UNEP-Report "The State of the Environment (1972-1992) - Saving our Planet", Nairobi 1992, p.118, states: "..noise has become a more significant problem than it was thought to be a decade ago. The problem is growing, in particular in many urban centers in developing countries. Noise is an major problem in Manila, Bangkok, Cairo and many other cities."

Over the next years, noise control should be brought up for discussion also in the developing countries because these countries will soon be faced with widespread damage to human health and considerable economic loss unless they are prepared to tackle this environmental problem. Experts of these coun[illegible]ould take reference to the health chapter of agenda 21 mentioned earlier. I think the people in the industri[illegible] countries have the moral obligation to strongly support upon request respective efforts of the developing countries.

We should begin by thoroughly investigating the developing countries special circumstances, comparing them with the industrialised world's own scientific findings. The results should be presented to the public and be imparted to policy-makers in particular. Then, the individual necessities should be defined at bilateral and multilateral level and be contrasted with the available experience and capabilities . Germany is prepared and glad to take part in such a cooperation by transferring the know-how acquired in this country over the last few decades and its technical administrative and legal noise abatement strategies which have proved a success in practical operation.

BASIC CONCEPTS OF NOISE REGULATIONS IN GERMANY AS COMPARED TO EUROPEAN GUIDELINES

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Abstract
In this paper the German regulations concerning immissions from environmental noise sources are presented and discussed in the context of guideline in some other European countries. Except for air traffic noise the procedure of ISO 1996 using rating levels for assessing noise exposure has been widely accepted. But there are a lot of differences in detail: definitions of adjustments, reference time intervalls and requirements for different times of day. This is true both for different sources and different countries. The noise descriptors for air traffic noise vary considerably allowing only very rough comparisons between the regulations in different countries.

1. Introduction

In the Federal Republic of Germany, as in many other highly industrialized and densely populated countries, noise is a severe environmental problem. According to a representative survey in 1992 more than 65 % of the citizens in the Federal Republic of Germany (without the former GDR) are annoyed by road traffic noise and more than 50 % by aircraft noise. Noise from railway traffic, industry or neighbours being named by about 20 % follow with a wide margin. Esp. for aircraft the situation has become worse since 1984.

Noise abatement has a long-standing tradition in Germany. Before the first specialised legislation on immission protection was enacted in the 1960s there already existed noise related regulation within the civil code, embodying civil and police law. These regulations contain elements, which have influenced attitudes in the Federal Republic of Germany down to the present day: e. g. noise restrictions at certain times (break at noontime, evenings, sun- and holidays) or "local custom". Thus, residential areas are expected to be less noisy than industrial zones. Therefore acceptable noise levels are matched to the designated use of the zones.

The most important legislation on noise abatement was enacted in the 1970s: the Air Traffic Noise Act [1] and the Federal Immission Protection Law [2]. The former defines noise zones around civil and military airports where special restrictions concerning constructing buildings with noise sensitive use and requirements for sound insulation of buildings are established (s. Sect. 2.5). The latter governs all matters concerning protection from noise and vibration especially for the establishment and operation of installations and the construction of roads and railways. Its aim is to protect human beings and animals from harmful effects from the environment and to prevent such harmful effects in particular by measures in accordance with the best available technology to limit the emissions. Furthermore, with the framework of regional

planning, land intended for a particular purpose shall be zoned in such a way that harmful effects on residential areas will be avoided as far as possible. Harmful effects are defined as immissions which, according to their nature, duration and extent, are liable to danger, considerable disadvantages and considerable annoyance to the general public and the vicinity.

The protection from harmful effects is in general guranteed by compliance with immission values which have been established for different noise sources. Following, the corresponding noise regulations in the Federal Republic of Germany will be presented and discussed in the context of regulations in other European countries.

2. Noise regulations in the Federal Republic of Germany

2.1 General remarks

The German regulations for assessing and evaluating environmental noise are widely in accordance with the International Standard ISO 1996 [3]. An exception is the regulation for air traffic noise. The fundamental quantity for the assessment is the rating level for different reference time intervals. The rating level is calculated from the equivalent continuous sound pressure level L_{Aeq} as the acoustical descriptor of the noise situation and adjustments taking different non-acoustical factors into account which affect the annoyance. The application of these factors listed below may vary from source to source:

- K_I adjustment for impulsive noise
- K_T adjustment for tonal components
- K_{Inf} adjustment for informative noise
- K_R adjustment for exposure during rest period (early morning/evening/sunday)
- K_{Sit} adjustment for special local situations
- K_{Source} adjustment for special noise sources (e.g. railway traffic)

For the protection of the population there are not only the rating quantities, the reference time intervals, and the immission values of importance but also the conditions under which the immission values have to be verified: location of immission, conditions of emission and transmission. This has to be taken into account when different procedures for measuring and assessing are to be compared.

2.2 Road traffic noise

The most important quantities for the assessment of road traffic noise are listed in Table 1. The rating level for daytime $L_{r,T}$ and nighttime $L_{r,N}$ resp. is made up of L_{Aeq} and an adjustment for local situations K_{Sit}, which takes into account the increased annoyance at crossings with traffic lights. L_{Aeq} is calculated from emission and transmission parameters, measurements are not allowed for. The decisive traffic numbers are taken from the yearly average value, and the transmission parameters correspond to weather conditions which result in high levels (down wind or inversion of temperature).

Immission values have been fixed for different applications. They are differentiated for time and location of exposure (s. Table 2). The values of column 2 are valid for land-use planning along roads [4]. Wherever it is possible the values should be fallen short, esp. for the protection of noise sensitive uses, but also for preservation or creation of very quiet residential areas. But the values are no limits which have to be verified strictly. In highly pre-exposed areas, especially near to existing roads the values may be exceeded when other aspects having to be

considered with planning are of higher priority. In this case, insulation measures at the building have to be carried out.

The values of column 3 are valid for newly constructed or considerably changed roads [5]. They are limiting values and have to be verified strictly. The values of column 4 are limiting values for existing federal roads. If the values are exceeded remedial measures - mostly insulation measures at the buildings - can be considered which will be supported by the Federal Minister for transportation. In some of the federal states the same values are applied for state roads.

A comparison with guidelines from other European countries like Austria [21], Italy [7], the Netherlands [8], and Switzerland [9] show that there are similar procedures for assessing road traffic noise. Seperated reference time intervals for daytime and nighttime are preferred to a single interval of 24 hours (e. g. L_{DN}: Day-Night Average Sound Level in the USA). The requirements typically differ by 10 dB which corresponds to the adjustment for exposure during the nighttime (23 - 7) of L_{DN}. In some countries the maximum values for L_{Aeq} of 50 to 55 dB(A) are preferred levels for residential areas being affected by road traffic noise. But these values are normally exceeded at existing roads. If at all, sound insulation measures are supported by the authorities if the levels are higher than about 65 to 70 dB(A).

2.3 Rail traffic noise

The most important quantities for assessing rail traffic noise are listed in Table 3. The rating level for daytime $L_{r,T}$ and nighttime $L_{r,N}$ respectively is made up of L_{Aeq} and an adjustment K_{source} of - 5 dB(A). This adjustment takes into account results from social surveys indicating that rail traffic noise is less annoying than road traffic noise [10]. At shunting yards an adjustment for impulsive noise and/or tonal components is applied depending on audibility and frequency of noise occurrences. As it is the case with road traffic noise L_{Aeq} is calculated from emission and transmission data.

The values for land-use planning and newly constructed roads of Table 2 are valid for rail traffic noise, too. Limiting values for remedial measures have not been introduced yet but they are in discussion.

As the problem of railway noise varies considerably from country to country regulations for rail traffic have only be set up in a few European countries, e. g. Switzerland and the Netherlands. It is a common feature that rail traffic is assessed to be less annoying than road traffic noise yielding a railway "bonus" which amounts to 5 dB(A). In Switzerland the bonus can grow up to 15 dB(A) at railway lines with a small number of trains per day only.

2.4 Industrial, commercial and leisure noise

Concerning industrial, commercial, and leisure noise the Technical Instructions for protection against noise "TA Laerm" [11] is decisive for the evaluation and assessment of installations that have to be licensed according to the Federal Immission Protection Law. In some federal states the guideline 2058 Part 1 of the German Engineering Association (VDI 2058/1) is used for these installations and for installations that need not be licensed according to law as well. Special regulations have been developped for noise from shooting ranges [12], sporting grounds [13], and construction sites [14].

The basis of the assessment are the rating levels $L_{r,T}$ for the daytime and $L_{r,N}$ for the nighttime on one hand, and maximum levels L_{AFmax} of single noise events on the other hand. Generally, the exposure will be determined by measurement. The definition of the rating level is different in the different regulations as concerns adjustments and reference time intervals. The most important characteristics are listed in Table 4. The corresponding immission values are presented in Table 5. Column 2 is valid for land-use planning, and for setting-up and operation of installations as well. Immission values for remedial measures are not established because the Immission Protection Law demands compliance with the values of column 2 (for licensed installations generally, for other installations as far as it is possible with the best available technology) and offers legal possibilities to carry through noise reduction measures. While the immission values for planning refer to the immission of all installations in the vicinity, there is no agreement whether this is true for setting-up and operation, too. In the last years these values have been applied mainly for the immissions of one concern. In course of the amendment of the "TA Laerm" which is going on at this moment this problem has to become clear.

In most of the European countries rating levels are applied when assessing industrial noise. But there are considerable differences concerning adjustments, reference time intervals, and limiting values. An overview over the adjustments for tonal components and impulsive noise is given in Table 6. The difference for K_I can amount to 5 dB(A). Table 7 shows the reference time intervalls. Differing from Germany, in some countries the day is subdivided in 3 reference time intervalls: daytime, rest periods, and nighttime with different requirements for protection against noise. In VDI 2058/1 the rest periods are taken into account by an adjustment of 6 dB(A) for morning and evening hours. Only within the ordinance for noise from sporting grounds a subdivision into more than two reference time intervalls is applied. The requirements within the reference time intervalls typically differ by 5 dB(A) between daytime and rest periods and by 10 dB(A) between daytime and nighttime. Only in Germany and Luxembourg the latter difference amounts to 15 dB(A). A comparison between the permissible noise level in different countries yields that differences up to 10 dB(A) can be found. But because of different compulsoriness of the regulations and the differences in details mentioned above this number has to be interpretated cautiously.

2.5 Air traffic noise

According to the Air Traffic Law noise zones have to be calculated in the vicinity of civil and military airports. Basic quantity is the level Leq(4) which is defined as follows:

$$L_{eq(4)} = 13{,}3 \ \log\left[\frac{1}{T_r}\sum_i t_{10,i}\, g_i\, 10^{L_i/13{,}3dB}\right] dB$$

with

$t_{10,i}$ 10-dB-down-time

L_i - A-weighted maximum noise level for every flight

T_r - reference time interval (6 months of a year with highest number of flights)

g_i - weighting factors for flights at daytime and nighttime

a)	$g_i = 1{,}5$	for daytime (6 - 22)	b)	$g_i = 1$	for daytime (6 - 22)
	$g_i = 0$	for nighttime (22 - 6)		$g_i = 5$	for nighttime (22 - 6)

The summation includes all flights in the reference time intervall.

For every immission location two values of $L_{eq(4)}$ are calculated. The higher one is decisive. In this equation, halving the time of exposure is equivalent to an increase of level by 4 dB. Thus, the averaging procedure differs from the one established in ISO 1996 where halving of time is

equivalent to an increase of level by 3 dB(A). In noise zone 2 (67 dB(A) $> L_{eq(4)} \leq$ 75 dB(A)), hospitals, schools, and other installations in need of protection must not be set up in principle. Dwellings are only allowed to be constructed if the sound insulation is satisfactory (weighted apparent structural sound proofing index $R'_w \geq$ 45 dB). In zone 1 ($L_{eq(4)} >$ 75 dB(A) it is not allowed to build up new dwellings in principal. The owners of existing houses can make a claim for sound insulation which must be better than 50 dB(A). A third zone with $L_{eq(4)} >$ 62 dB(A) will be calculated and given to the authorities of the states for land-use purposes.

Noise zoning regulations have been established in other European countries, too. They are combined with land-use restrictions and insulation measures as it is the case in Germany. Unfortunately, the acoustical descriptors vary considerably from country to country, and there are no close relations between the descriptors. Most of them use procedures of assessing noise that deviate from the principle of energy equivalency. In some countries adjustments depending of time of day are applied. Table 9 gives an overview over established and recommended insulation measures in diffeent noise zones with restrictions for new dwellings (for details see [20]).

4. Literature

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Table 1: Fundamental quantities for assessing road traffic noise in the Federal Republic of Germany

reference time interval daytime (6 - 22) nighttime (22 - 6)	 16 hours 8 hours
acoustical descriptor	L_{Aeq}
adjustments K_{sit} for increased annoyance near crossings with traffic lights	 3 dB(A) (up to 40 m) ... 0 dB(A) (more than 100 m)
decisive location	facade of the house (reflection at the facade not considered)
emission conditions	yearly average number of cars
transmission conditions	down wind or inversion of temperature

Table 2: Immission values for road traffic noise in the Federal Republic of Germany

areas	land-use planning	precaution at newly constructed and considerably changed roads	remedial measure at existing federal roads
1	2	3	4
	day/night in dB(A)	day/night in dB(A)	day/night in dB(A)
noise sensitive (schools, hospitals etc.)	no fixed number	57/47	70/60
only residential	50/40	59/49	70/60
mainly residential	55/45	59/49	70/60
mixed residential and commercial	60/50	64/54	72/62
commercial and industrial	65/55	69/59	75/65

Table 4: Fundamental quantities for assessing industrial and commercial noise in the Federal Republic of Germany

	TA Laerm	VDI 2058/1
reference time interval daytime (6 - 22) nighttime (22 - 6)	 16 hours 8 hours	 16 hours 1 hour (most disadvantageous)
acoustical descriptor	L_{AFTeq} [1)]	L_{Aeq}
adjustments K_I: impulsive noise K_T: tonal components K_R: rest periods (6-7;19-22) for uncertainties of measurement	 included in L_{AFTeq} 5 - 3 dB(A)	 L_{AIeq}-L_{Aeq} or L_{AFTeq}-L_{Aeq} 3/6 6 dB(A)
decisive location	0.5 m in front of open window	0.5 m in front of open window
emission condition	operation at full capacity	operation at full capacity
transmission condition	predominating weather situation	predominating weather situation

1) L_{AFTeq}: equivalent sound level of a time-weighted sound signal where every 5-s-time-intervall is represented by its maximum level L_{AFmax} (Takt-Maximal-Pegel)

Table 3: Fundamental quantities for assessing rail traffic noise in the Federal Republic of Germany

reference time interval daytime (6 -22)) nighttime (22 - 6)	 16 hours 8 hours
acoustical descriptor	L_{Aeq}
adjustments free railway : K_{source} shunting yard: $K_I + K_T$	 - 5 dB 2/4/6/8 dB(A) depending on audibility and frequency of occurrences
decisive locations	facade of the house (reflection at the facade not considered)
emission conditions	yearly average number of trains
transmission condition	down wind or inversion of temperature

Table 5: Immission values for industrial and commercial noise in the Federal Republic of Germany

areas	land-use planning/licensing and operation
1	2
	day/night in dB(A)[1)]
spa, hospitals	45/35
only residential	50/35
mainly residential	55/40
mixed residential and commercial	60/45
industrial and commercial	65/50
only industrial	70/70
indoors	40/30 (TA Laerm) 35/25 (VDI 2058/1)
[1)]VDI 2058/1: L_{AFmax} for single events 30 dB(A)/20 dB(A)/10 dB(A) higher during daytime/ during nighttime/ indoors	

Table 6: Definitions of adjustments for tonal components K_T and impulsive noise K_I in different European countries

	K_T in dB(A)	K_I in dB(A)
Austria [16] (only maximum of K_T and K_I)	3/6	3 if $L_{AImax}-L_{AFmax} < 2$ dB 5 if $L_{AImax}-L_{AFmax} \geq 2$ dB
Belgium [19]	-	$L_{AImax}-L_{AFmax}$ if ≥ 4 dB
Denmark [15]	5	5
France [17]	5	3/5/10 depending on duration and LAFmax-LAeq
Germany [18]	3/6	$L_{AIeq} - L_{Aeq}$ or $L_{AFTeq}-L_{Aeq}$
Great Britain [19] (only K_T or K_I)	5	5
Luxembourg [19]	-	5
Netherland[8]	5	5
Switzerland [9]	2/4/6	2/4/6 (depending on audibility and frequency of occurrences)

Table 7: Reference time intervals on weekdays in different European countries (most disadvantageous hours within the corresponding periods

	daytime	rest periods	nighttime
Austria]	(6 - 22) 8 h		(22 - 6) 0.5 h
Denmark	(7 - 18) 8 h	(18 - 22) 1 h	(22 - 7) 0.5 h
France	(7 - 20) operating time	(6 - 7; 20 - 22) operating time	(22 - 6) operating time
Germany			
industrial installations	(6 - 22) 16 h		(22 - 6) 1 h
construction sites	(7 - 20) 13 h		(20 - 7) 11 h
sporting grounds	(8 - 20) 12 h	(6 - 8; 20 - 22) 2 h	(22 - 6) 1 h
Italy	(6 - 22) 16 h		(22 - 6) 8 h
Luxembourg	(7 - 22)		(22 - 7)
Netherlands	(7 - 19) 12 h	(19 - 23) 4 h	(23 - 7) 8 h
Switzerland	(7 - 19) 12 h		(19 - 7) 12 h

Table 8: Immission values in dB(A) for industrial installations in residential areas in different European countries

	daytime	rest periods	nighttime
Austria	50-55		40 - 45
Denmark	45 - 50	40 - 45	35- 40
France	50 - 55	45 - 50	40 - 45
Germany			
installations	50 - 55		35 - 40
sporting grounds	50 - 55	45 - 50	35 - 40
Italy	50 - 55		40 - 45
Luxembourg	50 - 55		35 - 40
Netherlands	50	45	40
Switzerland	55		45

Table 9: Established or recommended sound insulation measures in different noise zones with limited capability for new residential buildings in different European countries [20]

	Noise zone	estimated L_{DN} in dB	noise insulation feature
Germany	67 dB< $L_{Aeq(4)} \leq 75$ dB	68 - 76	45 dB weighted apparent structural sound-proofing index
Netherlands	40 < Ke < 50 50 < Ke < 55 Ke > 55	67 - 71 71 - 73 > 73	30 - 35 dB(A) 35 - 40 dB(A) ≥ 40 dB(A) noise level reduction
Norway	60 < EFN < 65 65 < EFN < 70	60 ... 65 65 ... 70	EFN < 35; MFN < 60
Switzerland	NNI: 45 - 55	71 ... 77	window > 35 dB wall > 50 dB

STANDARDS FOR PROTECTING COMMUNITY HEALTH: THE NEEDS OF THE LEGISLATOR

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A standard must not be based on an opinion. In preparing environmental noise standards for the protection of community health, this is particularly important. Every facet of the standard, and any resulting legislation, must be backed by authenticated scientific research and be capable of withstanding the most severe examination. Personal experience and feelings have little place, except in getting the standard off the ground and formulating the first steps. From then on, each step must be accompanied by documentation from an acknowledged and acceptable source.

Health is defined as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity [1]. In the realm of protecting the health of the community, which is of prime importance in a democratic society, unless there is published data with an adequate scientific or epidemiologic data base, and preferably some backing by a reputable international body, any attempt at formulating a performance standard will likely be doomed to failure. One has only to look at the difficult path taken to enact anti-smoking legislation in the workplace, when, although everyone realised there are definite adverse health implications, there was a shortage of scientific evidence to back it up. Noise legislation is even more difficult to enact due to the insidious way that noise affects the human body, and the sheer disbelief in many people that noise can cause any harm to one's health. It is in providing the necessary background data and giving it international backing and prominence that the International Commission on the Biological Effects of Noise (ICBEN) can play a most important role.

Like a single drop of water falling on one's forehead, within the normal environment of man made sound a single loud sound is unlikely to harm. But repeated many times, the result may be disastrous. So it is not necessarily the intensity of the sound that matters so much as its energy. Or is it something else when hearing conservation is not the prime focus? There are still many unanswered questions and the need for realistic scientific research is just as important now as ever it was in the past. But there is a difference between the present needs and those of past eras. We have been through a learning process and on the way have accumulated knowledge, much of which was interesting at the time but has found little use in practice. The arguments between different frequency weightings and their relative merits is water under the bridge, and we have settled down to the realisation that the use of a single frequency weighting is quite adequate for almost all environmental measurements.

With time weightings and time bases, things are different, and as our American friends might say: "We are in for a whole new ball game". Until fairly recently we have not had the tools to research this field and the weightings that have been used are ones of convenience rather than of design. We have had the tools to research time bases, but generally this work has been overlooked in deference to the more glamorous research, at that time, into frequency weightings.

In our environmental noise standards for the protection of public and personal health one of the first questions is "How does one describe the adverse health effect that may arise from over exposure to noise?" That of a hearing loss is relatively easy, but that resulting from sleep deprivation due to noise is somewhat harder. Harder still is that due to the distant beat of modern "rock music" and perhaps hardest of all that due to incessant low level immission of low frequency sound from some industrial processes. That this latter is dangerous to health takes a lot of believing - until someone dies through what may seem is a direct consequence of such immission. The work of Barbara Griefahn on sleep disturbance [2] and circulatory disorders [3] through exposure to noise is much to be admired. But now I suggest we should extend our reference point to the physical immission in real life and determine what parameters, measured at the property boundary, provide the key to the disbenefit, and how they may be described and quantified.

In New Zealand a series of national Standards on the management of environmental noise for the protection of community health is being formulated. Already in operation is one on Airport Noise Management. The formulation of this Standard brought to light a number of areas in which much more information is needed and much more scientific research necessary. For example it was obvious there was the need for some protection of local residents' sleep from disturbance by the noise of night-time flights. But how? The New Zealand Standard NZS 6805 [4] tells the users of the airport exactly how much sound exposure they may make over any residential area and only in a fixed airport control zone, enclosed by the "Airnoise Boundary" may they make more than this amount of noise. For the protection of community health the maximum daily measured sound exposure at the Airnoise Boundary is set at 100 pasques (pascal-squared-seconds), and is A-frequency weighted.

To operate in accordance with the Standard, the airlines must plan their flight numbers and aircraft used so that their noise allocation is not exceeded at or outside the airnoise boundary, and a series of noise monitoring stations at the boundary, ensure they do so. Very strict land use in this area compensates for the extra noise inside the airnoise boundary, the position of which the local authority is responsible for determining - the larger it is the more airport operations are possible but the more costly are the land use control measures within that boundary. Unfortunately such a control does not protect from startle and sleep disturbance at night, and local authorities must consider whether some control at night is necessary. The airlines and the airport owners want no restrictions whatsoever. The residents want no flights whatsoever. Obtaining a balance between the needs of one and the rights of the other is difficult. If an aircraft is quiet enough not to disturb sleep, one may question why it should not be allowed to fly (considering noise only of course).

Then comes the main difficulty - "How do we describe the controlling parameter(s) and what values do we assign as the limit for permissible noise at night *at the property boundary*?" - for that is the only place at which a control can be made. Then are there different awakening thresholds for different rise times and durations? Similarly do we have different tolerance levels for different sounds - possibly again involving rise time, duration and spectral content? Whatever we do, we need a feasible unit of measurement that can be contained within a small hand held sound level meter, and criteria for protection that can easily be incorporated into performance standards and legislation.

At this point I believe we need ICBEN to consult with the nations represented and to come up with an international consensus for use - ie ICBEN to function as a promulgator of performance standards for the protection of health from the adverse effects of noise.

Not dissimilar to the research on sleep disturbance is that needed on the disturbance from the low frequency beat of modern "rock music" in adjacent premises. Sometimes the noise levels are so low that measurement is next to impossible with a simple sound level meter. But, nevertheless, the disturbance may be very serious to the recipient and produce considerable stress. It would be good to be able to produce legislation to protect innocent parties from this modern affliction. But on what does the legislator base his performance standard? Peak levels may be the answer, but again we have a problem in that there always is present in the atmosphere a large amount of low frequency noise that will be picked up by a sound level meter. For example, even a car door closing 500 metres away may be sufficient to give a peak reading on the meter. Thus we need some frequency limitation and a time-weighting limitation to adequately describe the noise. Again the unit must be something practicable that sound level meter manufacturers can utilise.

The use of C weighting for peak level measurements has been suggested and is in use in may parts of the world simply as a means of limiting the low frequency noise that may be picked up on our meters, and not because the C weighting is advantageous throughout the frequency range. The IEC standard in preparation to replace IEC 651 and IEC 804 is expected to include limiting frequency cut-offs for peak measurements. But although good for some of the peak measurement needs whether this will help in solving the low frequency "beat" from modern "rock music" remains to be seen. And of course there is always the uncertainty: Is not some annoyance a good thing now and again? Does it always cause stress and fatigue or can it stimulate a healthy reaction in some circumstances? The answers to these sort of questions would be most useful.

A continuing problem is that of protecting health from the adverse effects not only of exposure to excessive noise in industry but also of exposure to more noise in what is supposed to be the recuperation period of evenings, night-time and weekends. In many countries both husband and wife need to work in order to balance the family budget. If one is deprived of working, then often the other works longer hours or undertakes two, or more, separate jobs in order to survive. The health risks are compounded. Our legislation is usually based on an 8 hour working day and a 40 hour working week with the remainder of the time quiet and conducive to a recuperation of the hearing mechanism. The usual measure is one of total sound exposure or an integral of sound exposure levels - an energy measure. Whether or not this is the best measure is still being argued. But the legislator can only go on what is adequately documented and has general acceptance.

The limiting criteria chosen inevitably are the result of political deliberation. One has to balance the costs to industry of the noise reduction necessary, and the resulting costs to the country in reduced output, with the benefits to the worker, knowing that in general the effect of the noise exposure will take some long time and that the worker is unlikely to remain in that noisy occupation all his working life. The risks are reasonably understood for an 8 hour working day, 40 hour working week. But where does the legislator go for advice when the working day is likely to well exceed these times? It is not uncommon for people to work a 12 to 16 hour day in excessive noise, and weekend working is very common. In this case, should the legislator produce relevant upper limits of noise exposure and what should they be?

Disregarding for the moment the arguments of whether the measure should be one of energy or something else: If the hearing disbenefit is one of weekly received sound energy taking out of the hearing mechanism an equal or related amount of energy, then it may not be out of order to consider that the recuperation process is one of the human body pumping back that energy into the system. It is likely there is a maximum rate at which this energy can be produced and hence, if we are to protect hearing, the maximum weekly noise exposure should not exceed the number of "rest" hours multiplied by this maximum energy replacement rate.

Calling the rate "P" (pasques per hour) the maximum permitted sound level for an "X" hour weekly exposure would be

$$10\log\{(168-X)P/(20\times10^{-6})^2.3600.X\} \quad \text{or} \quad 10\log(168/X-1)+10\log P+58.42 \quad \text{dBA}$$

P needs to be determined, but as a first guess, if the internationally used criterion of 85 dBA for eight hours a day, five days a week is sufficient to protect the majority of people, then P is about 140 (pasques per hour), and the equation reduces to:

Maximum permitted sound level = $10\log(168/X-1)+79.9$ dBA

In limit this does not make much sense, but within the envelope of most working hours may not be too far wrong, For example, people working a 12 hour, six day week would be limited to 81 dBA and not 83 dBA as a straight energy conversion would suggest.

The author realises he has made some far reaching assumptions:
1 Hearing loss is related to sound energy received,
2 The sound energy is balanced by a related energy exchange in the hearing mechanism that must be replaced,
3 The rate of energy replacement is linear with time,
4 The ambient level of the recuperation period is constantly below the critical level, whatever it is, at which there is no effect on the hearing mechanism,
5 There are no other factors coming into play that may affect the recovery of the system.

It would be appreciated if someone could produce some definitive research results to confirm or otherwise that the author's method in determining the criteria for other than a 40 hour week is reasonable.

It may be argued that occupational noise is not of concern in environmental noise standards. But one cannot separate out the two functions and assume they are quite independent. If the period for recuperation has an ambient noise level greater than a critical amount then no recovery will be likely and the environmental (and recreational) standards must take this into account. Unfortunately scientific evidence for this is hard to find and the legislator must go out on a limb to set such a terminal level. For the want of anything better, this author, in the standards he has formulated for New Zealand, has used 65 dBA as the level at which there will be no hearing loss (75 dBA outside at the property boundary), and 55 dBA as the level at which the recuperation process may be accomplished without hindrance (65 dBA outside at the property boundary). He may well be very wrong, and some definitive research would be appreciated.

Linked to this problem is the belief of some people that sound that is wanted does not harm health. Following concerted efforts at high level, some of the more responsible manufacturers of personal cassette players are putting warning notices with their products that exposure to too high a noise level may cause hearing damage. Nevertheless, many young people are experiencing severe hearing loss at an early age to the detriment of their future health. Yet they refuse to believe it the result of their "musical" activities.

Rock concerts are of particular concern. By law, most of us can only control the noise emission from the premises to a neighbouring residential premises - not the noise at site, for that would be an infringement of human liberty. Initially bands took no notice of the regulations and if there was a fine involved, assumed they would be subject to it, and simply increased the price of the tickets sold to cover it. We don't have that problem now at the major venues: By local bylaw, any band that exceeds the level and does not immediately correct the situation, is banned from ever playing in that city/town again. It did not take long for this bylaw to be recognized and for bands to obey the rules. But that does not protect those paying to listen to the concerts and education seems not to work. So another need is for noise limits to be set so that the health of the audience in such concerts is protected, and some international backing so that the human rights arguments can be withstood.

It is now recognized that long term exposure to continuous low levels of radiation are detrimental to health and the BELLE [5] organisation has been set up to research into these effects. The same could apply to long term continuous exposure to low levels of low frequency noise. In New Zealand we recently had a case of annoyance and health concerns over a wide area caused by the 24 hour emission of low frequency noise from an industrial plant. The levels were hardly measurable but caused a large number of complaints. Eventually an agreement was reached for the removal of the plant, but not before some members of the community had felt their health was suffering so much that they were forced to move out of the locality, and the local vicar, who was one of those most affected, had died from heart failure that many attributed to the noise. There is no scientific evidence for such a cause. But an overall improvement in the health of the local people is reported. So this is an area in which some good research would be of benefit.

Another area of concern is that of exposure to noise and vibration in travel, and its effects long term. One problem we seem to get in New Zealand is an excessive amount of spinal injury in cabin crew of aircraft - injury similar to that of whiplash, although no such occurrence is reported. The thought is that the combination of noise and vibration may affect the balance of the crew and that in their daily work their body posture may be such that the spine does not withstand the sudden changes in aircraft attitude that occur.

In Summary: This paper has dealt with a few problems to which some answers would be very welcome. The legislator must have substantiated scientific evidence for any standard that may be produced, however worthy the cause may be. Although we have a wealth of information on the biological effects of noise, there needs to be a collation for the legislator, for it should not be assumed he or she will have any knowledge of the research result or where to find it. There also is still a number of unanswered questions:

1. How does one describe the adverse health effect that may arise from over exposure to noise? What metric should be used?

2. In producing standards to protect sleep, should we consider using a different time base or time-weighting?

3. What metrics should we use in a standard to control the reception of low frequency rhythmic sound from modern "rock music", and what should be the control?

4. Is the author's method in calculating the permitted upper level for an occupational noise exposure greater than 8 hours a day, 5 days a week, reasonable or does research show a better method or one with a better scientific base?

5. What is the upper limit of continuous sound that will produce no hearing loss? Is an ambient level of 65 dBA Leq a reasonable figure to use in standards for this purpose?

6. What is the upper limit for the sound level that will permit hearing to regenerate after a full dose in industry? Is 55 dBA a reasonable level to use?

7. For the protection of health, is there a level, on which we could have international agreement, that could be legislated as the maximum for anyone in the audience of a rock concert?

8. What do we do about continuous exposure to low levels of low frequency noise and vibration? Can we find some means of defining the exposure, its effects on health and a suitable metric to use?

9. Is noise and vibration a contributing cause of spinal injury in aircraft cabin crew and are there criteria we should use in standards to protect their health?

This paper has concentrated on the needs of the legislator in producing noise performance standards for the protection of environmental health, and illustrates a few of the problems. It does not purport to cover all aspects of standards on environmental noise for the protection of community health. and covers a small segment only. If it stimulates research to produce some definitive answers, and will encourage ICBEN to start taking a leading role in advising governments on criteria to use for the protection of community health, then this humble author will feel his effort has been worthwhile.

References:

[1] World Health Organisation Constitution.

[2] Griefahn B " Environmental Noise and Sleep. Review - Need for Further Research" Applied Acoustics 32 (1991) pp255.

[3] Griefahn B. "Impulse Noise - Effects on Cardiovascular Functions" Proceedings of Internoise-91 pp839, Sydney.

[4] NZS 6805:1992 "Airport Noise Management and Land Use Planning" publication of Standards New Zealand, Private Bag, Wellington.

[5] The BELLE Organization (Biological Effects of Low Levels of Emission) School of Public Health, University of Massachusetts.

Airnoise Boundary Concept for Environmental Noise Management

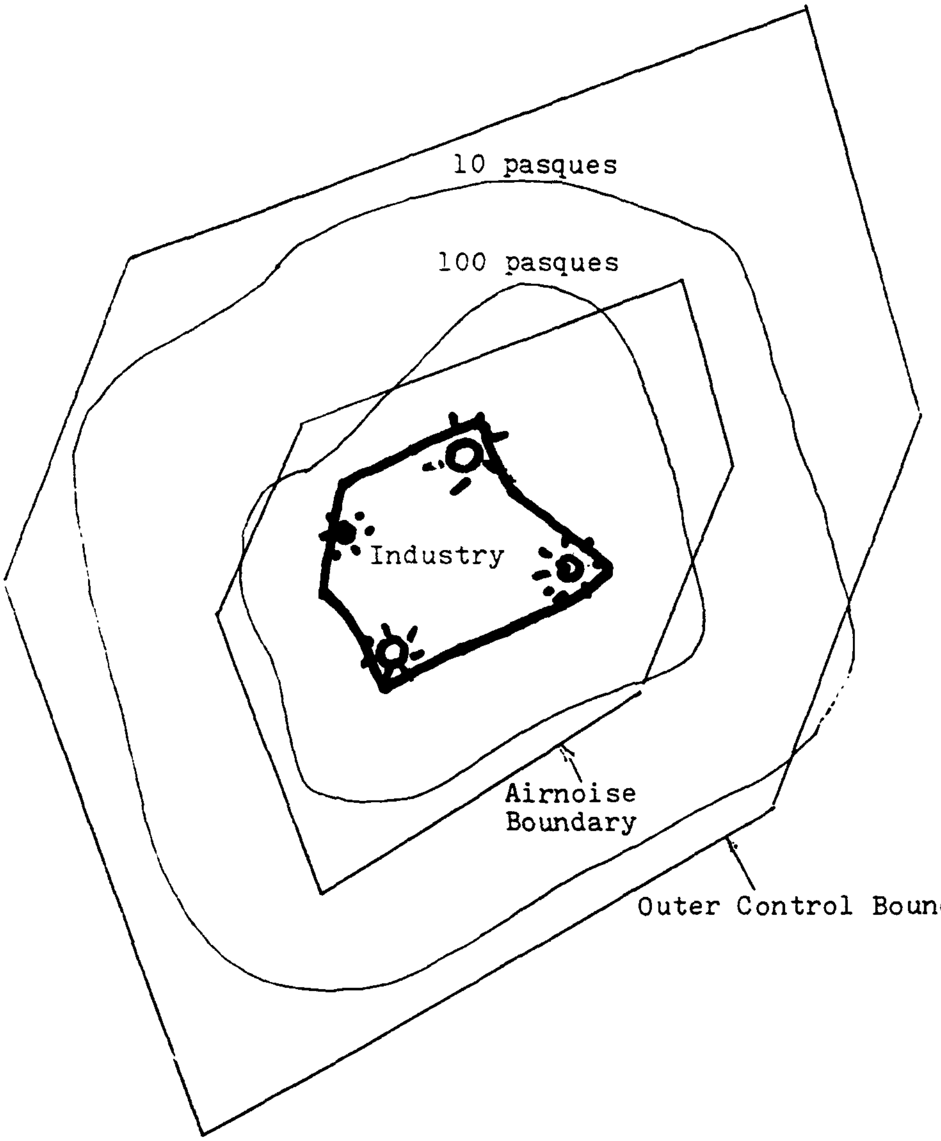
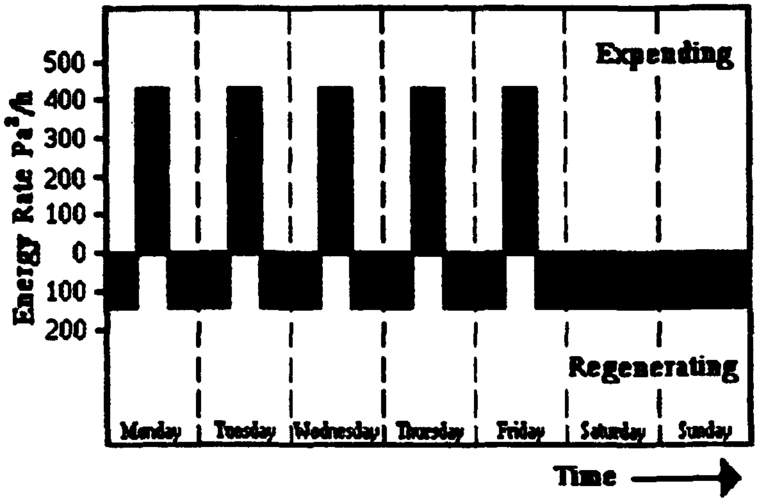


Figure 1

One pascal-squared-hour per day for five days per week
balanced by input of 140 pasques per hour for 128 hours



Six working days of twelve hours per day
balanced by input of 140 pasques per hour for 96 hours

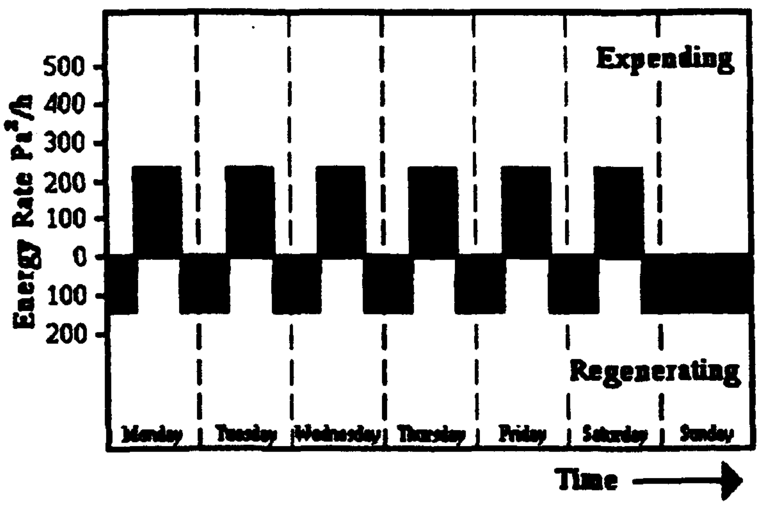
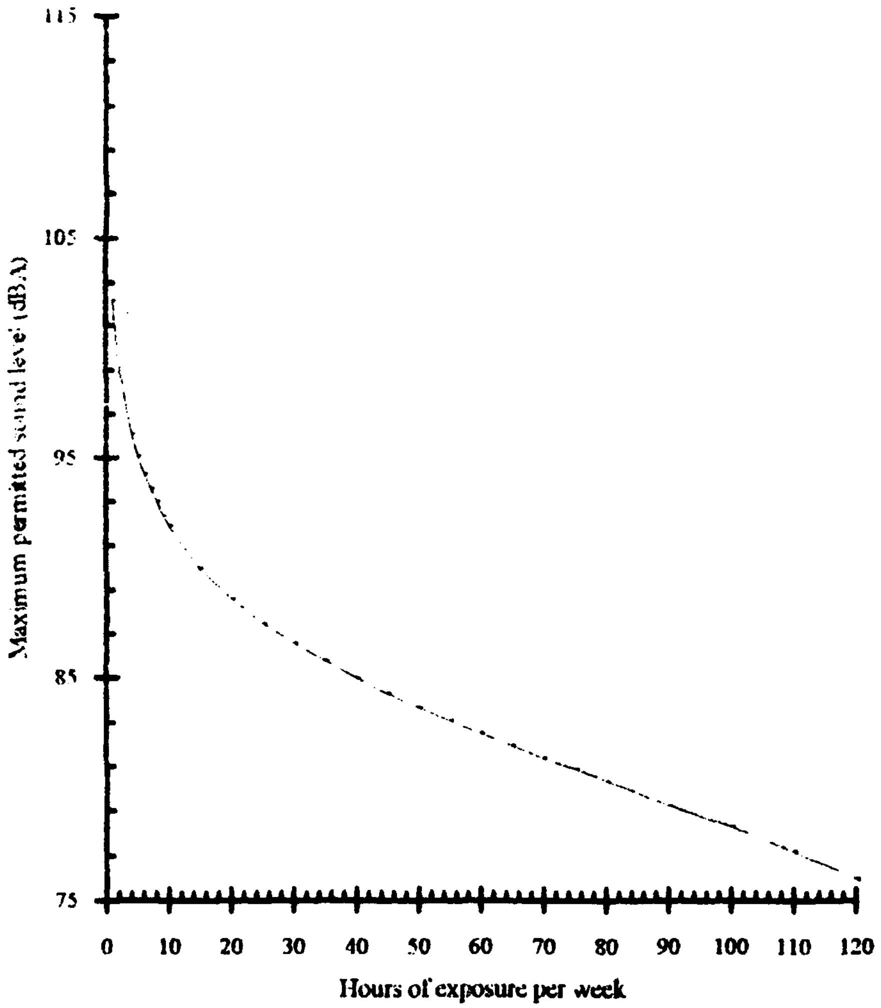


Figure 2

Maximum permitted equivalent sound level for weekly hours of work



TRAFFIC NOISE

ZARAGOZA TOWN COUNCIL
JAVIER CELMA CELMA
Environment Service Head

Nowadays it is unanimously agreed that traffic noise should be considered as a polluting agent which intensely affects the communities in their continuous town development proces ses, interfering to different extents on the activities which the citizens carry out in their normal surroundings, the city.

THE SITUATION IN SPAIN

Over these last few years campaigns have been carried out in different Spanish cities to measure the sound levels. Some of the results obtained are:

- Practically half the surface area of the municipal district of Bilbao has equivalent sound levels which exceed 65 dB (A), whilst 5 to 10% exceed 75 dB (A).

  In the outlying districts, the mean sound levels vary from 60 dB (A) and 68 dB (A) during the day and 49 dB (A) and 55 dB (A) during the night. In the country areas, these mean levels vary from 52 dB (A) during the day and 45 dB (A) during the night.

- In Barcelona and in the Elxample District (745.2 hectares) 68% of the surface area with greater traffic, have equivalent sound levels varying from 70 dB (A) and 80 dB (A) for the daytime period.

  During the night the sound levels vary from 65 dB (A) to 75 dB (A) on 65% of the surface area.

- In Madrid, 42% of the town area, bordered by the M-30, register sound levels of over 70 dB (A) with margins of variation between measuring points or areas of between 80.4 - 81 dB (A) and 48.5 dB (A).

- In different towns of Alava, the sound levels measured varied from 70.8 to 74.4 dB (A) for the daytime period and 64.2 to 66.2 dB (A) for the nighttime period.

- Within the Autonomous Community of Madrid, 30% of the points measured (200) out of the twelve industrial towns with greatest population density exceed 65 dB (A), whilst in the country villages and in summer, this level is only exceeded in 18% of the measurements made (70 points). Altogether, 27% of the points measured exceed the above mentioned sound level.

- In Zaragoza and according to the noise chart, 34% of the measurements made exceed 65 dB (A) for the daytime period and during the night 40% exceed 55 dB (A) (see figures 1 and 2).

An analysis of the situation of the Spanish cities with respect to environmental noise shows that a great part of the population is subject to levels which can be considered as excessive and which can cause problems, the noise from ground traffic generally being the main cause.

The noise charts are the main diagnosis elements and are an essential instrument for designing and planning rational mechanisms for reducing noise, which will have to be immediately implemented in the large cities.

In Zaragoza, the noise chart has just X-rayed the city, showing how the radius of the large communication axes begin at the historical centre, constituting the urban part of the modern

city, where the traffic flows are confused with the noise levels.

In Zaragoza, we have been able to verify that the areas where the noise chart detects higher noise levels, coincide with the isolines of greater concentration of atmospheric polluting agents (NOs, SO2, O3, Suspension particles, etc.) and with the greater temperature increases which are created in the thermal island of the city, as can be seen on the thermal chart.

The noise, air quality and thermal charts practically all coincide at their critical points with the traffic flows, making us consider the need to join forces in the fight against traffic noise and atmospheric pollution, taking into account that the problems have the same sources.

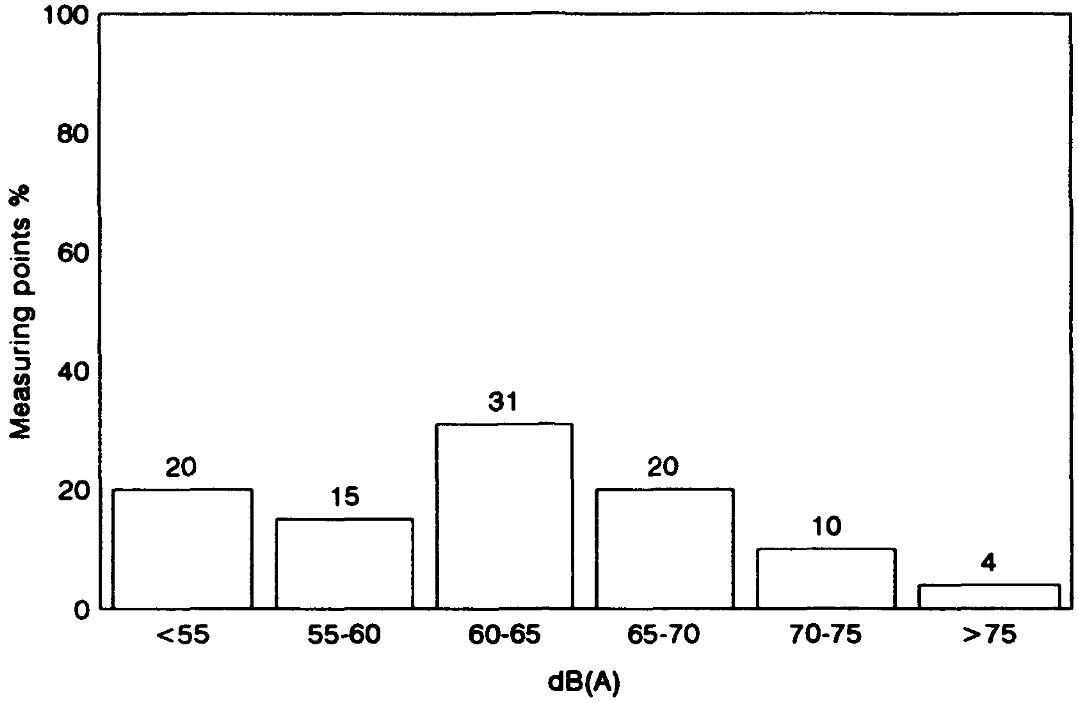
NOISE SENSITIVITY

The social demand for a decrease in environment noise levels, has increased greatly over the last few years.

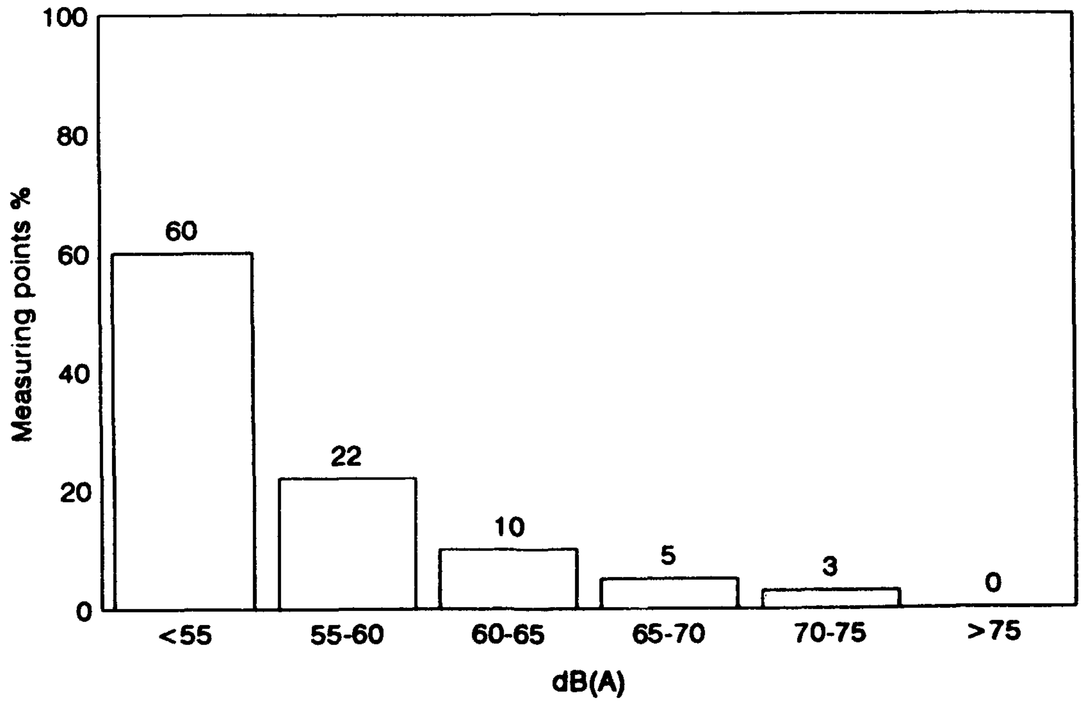
In Barcelona, different opinion polls on the factors which make it unpleasant to live in the city, place noise in third place. In Zaragoza, in a psychosociological study carried out recently, it can be verified that traffic noise is most important for the citizen than other town noises, and is described as "quite worrying". The same occurs with how intensely the citizens feel personally affected by different social matters, traffic noise being among the matters which most affect the citizen personally (5th place out of the 18 aspects presented).

The social perception of the phenomenon and its vindications are in line with the current European cultural patterns, which have been reached through a long process whereby the individual's relationship with his surroundings has matured.

ZARAGOZA NOISE CHART
DAYTIME Leq RATE (NED)



ZARAGOZA NOISE CHART
NIGHTTIME Leq RATE (NEN)



CONCLUSIONS

The conclusions which can be reached from the different actions taken against noise, verify that noise charts are essential instruments for diagnosing the reduction of sound levels in the cities, as they provide us with a series of data which enable us to reflect, from practically unknown viewpoints, on the possibilities of reducing environmental noise through municipal intervention in such important aspects as town development, traffic planning, goods transport .... All of these aspects are absolutely necessary to shape the dynamics of the town ecosystem.

Nowadays the typical technical or legislative actions which are normally taken against town noise are essential but insufficient. Traffic is the source of noise in towns and the models of our cities with the current land planning are the cause.

In this sense we would have to advance along three lines:

1 - Internationally, the emission levels from mobile sources must be more severe.

2 - Psychosocial analyses must be introduced to discover more precisely to what extent the citizens are bothered by noise, as well as the solutions set forth forth to reduce it, with the participation of the public in general.

3 - Part of the solutions must be framed in the cities with an utopic objective of land development, giving priority to: Shorter distances between place of employment and home, priority to collective transport, dispersion of tertiary uses, traditional shops near to the homes, etc.

ORIGINAL AND SPECIFIC REGULATION FOR COMPENSATION AGAINST NOISE AT EDF-GDF COMPARED WITH FRENCH REGULATION AND STANDARDISATION SOME REMARKS ABOUT THE FOLLOWING TABLES.

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Compensation preceding technical Prevention
In the first place a compensation for the exposure even without hearing damage has been the leader preventive means against noise decided in the statute of the nationalisation by law for EDF-GDF (1946)
Before the french regulation of the professional disease (1946-1963) and the first standards (1965-66)

The chronogical evolution of the noise abatement campaign has begun by the recognition of a noise nuisance in 1913 in the french regulation (10 July 1913).

The specific effects of noise being for ever and without any medical solution, only one action is possible :

PREVENTION

In the first place a compensation has been given for :
- the specific professionnal disease : hearing loss (T 42)
in function of the social handicap

- But some month's before, the statute (Nationalisation by law) of E.D.F.-G.D.F. in April 1946, has adopted an original clause :
the compensation for the noise exposure even without any hearing damage beyond a danger limit of 95 DB B defined from an internal study.

This compensation, is given, at the moment of retiring without pension loss from 55 years old.

In these terms, this standard is a kind of prevention against noise but it is only an alternative solution, awaiting for technical reduction of noise at the work places.

The prevention by
french regulation and standards have followed :

1 - Determination of noise levels - noise sources ,and measuring of noise doses for one week of work (40 hours)

2 - Evaluation of the risk
and definition of noise danger limits for conservation purpose of hearing

- at E.D.F. = 95 dB B (1967)
- in French regulation = 85-90 dB A (1969)
- in EEC Directive = 85-90 dB A (1986)

Some standards have given the bases and measurement methods :

- Assessment for occupational noise exposure for hearing conservation purposes (ISO 1999 - NFS 31 013)
- Evaluation of the noise effects
- Threshold of hearing as a function of age and sex (NFS 31082)
- Definition and compensation of the specific professional disease (T. 42 in the french regulation of the Social Security - 1946-1963) and the same for the professional accident by noise.

Then, with the development of the scientific knowledges in acoustics the regulation has been more specific for the :

- Measuring conditions of noise level (1972)
- entiled laboratories
- correcting measures for noise reduction (1973)
- a basic general decree for the workers protection against noise in 1971 which has been revised in 1988.According to the EEC Directive (1986) but the danger limits were not changed.

- to anticipate the professional hearing loss an audiometric medical survey has been assessed in FRANCE in 1977 adapted in each medical of work unit's centers in E.D.F. and assessed by the EEC Directive in 1986.

- the intelligibility of speech in noisy conditions has been also estimated (assessment of speech intelligibility distances) and now in the working groupe 8 (WG 8) of CEN a standard in three parts is prepared on this subject in accordance with the EEC Directive : "Safety of Machinery".(Ergonomic assessment of speech communication)

- The personal hearing protectors has been recommended before the correcting measures for noise reduction and :
in 1978 a french standard has been edicted (S 31 062) : measurement of sound reduction by personal hearing protectors,

and after (ISO TR 4869-3 in 1989)
Hearing protectors method for the measurement of insertion loss...

The evolution of the technical measuring methods of noise and its effects ; the evolution of materials and the noise reducing methods have only satisfied the basic and original advices of the EDF-GDF first regulation. But the compensation of risk without any hearing damage is still now into practice.

DATES		E.D.F - G.D.F.	FRENCH REGULATION	STANDARDISATION AFNOR	CEN/ISO
1913	10.07		Recognition of a noise nuisance		
1946	8.04	Nationalisation by law (statute)			
	11.10 31.12		Medicine of work by law Statute of the organisation of the Social Security		
1956		Practical hand book to apply the statute			
1959		Preliminary studies of noise nuisance			
1963	03.08		Professional disease (T 42) Definition - compensation and compulsary declaration		
1965	Sept.			<u>S 31004</u> Physical and physiological noise characteristics	
1966	June			<u>S 31005</u> Determination of noise levels	

DATES		E.D.F - G.D.F.	FRENCH REGULATION	STANDARDISATION AFNOR	CEN/ISO
1967		definition of noise danger limit at 95 dbB Evaluation of the hearing loss of exposed people versus normal population			
1969	1er.04		Emergency decree : compliance with noise limits (85 et 90 dB A)		
1971	26.11		Application of edict in pursuance of the decree for the powers protection against noise		
1972	16.03		Measuring conditions of noise levels Entitled Laboratories for noise measurement		
	02.11		Revision of the T. 42 professional disease		

DATES		E.D.F - G.D.F.	FRENCH REGULATION	STANDARDISATION AFNOR	STANDARDISATION CEN/ISO
1973	03.01		Correcting measures for noise reduction		
1974	Décem.			Noise measurement in Noisy environment S 31010	
1975	August			S 31013 - Evaluation of the noise effects of exposure	ISO N 1999 Assessment of occupational noise exposure for hearing conservation purposes
	Mai			S 31047 - Assessment of speech intelligibility distances in noisy conditions	
1977	11.07		Medical survey of exposed workers	NF. S. 31025 - Determination of the acoustical power of noise sources	
1978	Sept.			S.31062 Measurement of sound reduction by personal hearing protectors	

DATES		E.D.F - G.D.F.	FRENCH REGULATION	STANDARDISATION AFNOR	STANDARDISATION CEN/ISO
1981	11.03		2ème revision of the T. 42 Professional disease	S. 31 081 Audiometric survey method	
1983	01.12				N.ISO 6189 Acoustics pure tone air conduction thres hold audiometry for hearing conservation purposes
1985	April			S.31013 Revision S. 31082 Threshold of hearing as a function of age and sex	
1986	12.05				EEC DIRECTIVE 89-391 Workers protection against noise

DATES		E.D.F - G.D.F.	FRENCH REGULATION	STANDARDISATION AFNOR	STANDARDISATION CEN/ISO
1987	August			S 31084 Measuring method of occupational noise levels for the assessment of self daily noise exposure level of works S31003 Revision Normal isosonic curves	ISO N6 226 Isosonic curves
1988	21.04			Application in the french law of the EEC Directive 89.391	
1989	31.01		Regulation of the workers audiometric survey (Revision)		
	15.11				ISO TR 4869.3 Hearing Protectors Method for the measurement of insertion loss...
1990	march			S 31 115 Part.1 Definition and method of assessment of voice on put systems	

DATES		E.D.F - G.D.F.	FRENCH REGULATION	STANDARDISATION AFNOR	STANDARDISATION CEN/ISO
1991	Sept.			S 31 115 Part.2 Assessment of automatic speechs processing systems	
	31.12		Code du Travail Modification		
1992	31.12		Noise law (in environmental conditions)		
1993	February			S 31 062 Hearing protectors - Subjective of sound attenuation	ISO 4869.1 method for the measurement
	March			S 31 010 Revision Description and measurement of environmental noise to support the application of the Noise Law	

Applied Noise Research and its Effects on Regulations and Standards.

Jansen, Gerd

1. Human health is characterized by (1) absence of illness and by (2) an optimal well-being status.

This means that research has (1) to refer to the question of functional disorders in human beings caused directly by noise and (2) to the question of well-being.

(1) Noise induced functional disorders are only known with hearing loss which are monocausally created with sound in a dose/-response relation. After being damaged the hearing organ cannot be treated expect with hearing aids for the rest of hearing capability.

(2) In non-auditory fields functionals disorders (e.g. illness or disease) cannot be raised by noise alone in healthy people. Therefore, noise is regarded as a human health hazard which may additionally lead to illness. In these respects noise is a risk factor for human health.

2. In this situation it is necessary to study the noise effects in non-auditory fields and continue with a medical assessment of these effects. The range of these non-auditory effects is very broad and shows a high variability. Laboratory studies with animals and human beings as well as epidemiological studies have shown that noise is a stimulator of the autonomous nervous system. But this fact alone cannot be regarded as dangerous for human beings.

3. Laboratory experiments are the basis for several biological models of noise causing diseases; but the epidemiologic evidence of the harmfulness of chronic noise exposure is weak. So, neither cardiovascular diseases nor hypertension by noise can be either confirmed or rejected. Here, longitudiual studies are necessary. The design of such studies should be developped in cooperation with medically, statistically, epidemiologically and otherwise trained experts in order to have reliable, valid, and objective results with a minimun of financial expenses.

4. Included to this and additionally to these studies the examination of critical groups like old people, babies, ill people, and/or pregnant women should be taken into account. This refers not only to the physical functions but also to mental health.

5. As conclusions of the above mentioned facts we give the following statement:

The evaluation of noise induced health hazards should be based on the results of scientific investigations. Physiological responses due to noise impact show in the range of middle-loud and loud sounds a more or less close dose-response curve. Psychological and sociolgical effects of noise do not provide close dose-response relations. Therefore, other methods and criteria have to be used for the evaluation of noise effects.

Based on experimental data and practical experience in most countries, levels of 85 dB(A) $\pm$ 5 dB(A) are regarded to be harmful for the hearing organ. Legislative provisions (national) or recommendations (international) are adapted as guidelines or limits for noise exposure at workplaces. For many other fields of noise exposure limits or guidelines have been established which often differ widely between several countries. The question arises if it would be desirable, useful or even compulsary to establish common guidelines or limits on an international level. Combined wich these situation the question arises if scientific research is sufficient for such an establishment of regulations.

The newly founded team 9 of ICBEN "Regulations and Standards", which took place at the end of the Stockholm Conference in 1988, has had its constitution at the Nice Conference 1993 and will deal within the near future with these questions. It has to be decided if it would be helpful for noise control to establish risk tables and commonly accepted guidelines for the various fields of noise loads (community noise, occupational noise etc.) and for the various field of noise effects.

WHO, European Community (EC) and other supranational institutions have published various overviews and papers concerning regulations and standards. The work of Team 9 of ICBEN has to concentrate on the evaluation of scientific results (experimental and epidemiological) and on equalization and (necessary) differentiation of standards which are contained in the papers mentioned in the meetings of this conference.

The papers and communication of the present conference are the beginning of Team 9 work. It is expected that national and international authorities will promote and assist members of Team 9 in their work.

Summary of Team 9

After having established Team 9 "Standards and Regulations" at the very end of the 1988 Stockholm Meeting of ICBEN, it was the first time to present the team to the public. The team sessions contained 10 Invited Papers and 11 Free Communications.

The authors dealt with various topics, which can be summarized in an order of decreasing importance as follows:

1. Compared to other environmental factors, the attention paid to noise by the environmental policy seems to have diminished.

2. It was stated that peaks of noise and additional noise parameters have to be considered besides L_{eq}, when assessments of noisy situations are necessary.

3. Comparison of different national regulations with respect to level calculation and its correcting factors (K_{inf}, K_{Tone} etc.) have to be taken into account.

4. Regulations in road traffic noise and entertainment in urban areas were discussed with respect to limits and time assessment.

5. Standards for health protection need more basic research and exchange of scientific results.

6. The need for town planning refers not only to the possible noise impact but to other factors that coincide and contaminate with noise like air quality, radiation, and others.

7. Common and specific regulations have been discussed concerning hearing loss in various occupations and the problems of its compensations. The present situation in different countries has to harmonized within EC. It could be a pattern for other states in the world.

All these common and specific questions - more or less unsolved - should and could be cleared up by way of applied noise research. Therefore, questions and problems should be listed up and brought into a priority list. Human health is a decisive factor in that respect and should be included in the research policy. But this research has to take into account the multidimensional aspects of health disturbances. Team 9 should play an active role in the solution of all these questions.

3. Goals of Team 9 were discussed and accepted at the businesss meeting

Assistance and Participation in national and in international regulatory bodies.

Topics of the team's work the the near future:

1. Comparisons of existing
   Guidelines and
   Recommandations on national and international levels

2. Information of essential research needs especially on overall noise load to team members and interested bodies (specialists) in national and international investigations

3. Information of costs and cost effectiveness of noise control

4. Developing of adequate activities for high and low industrialized nations for adequate noise control (like planning)

5. Recommandations for establishing standard methods for noise measure for human effects on the basic of ICBEN--Teams summaries and recommendations.

6. Clarify if central values for references in the different areas of noise load can already be established either as orientation values or as threshold or danger values

The chairman and the co-chairman will established a strategy of promotion and a time schedule for activities of Team 9 within the next months; and they will inform the Team members and the officers of ICBEN about these activities.

POSTER AWARD SESSION

The Jury formed to judge the best poster at the Noise and Man'93 Congress

The members of the jury were :

Mrs Eeva PEKKARINEN, Institute of Occupational Health, Helsinki, Finland
Mr Patrick BRADSHAW, EOARD, London, UK
Mr Michinori KABUTO, Japan Environment Agency, Ibaraki, Japan
Mr Warren RENEW, Department of Environment and Heritage, Brisbane, Australia
Mr Richard TAFALLA, University of Wisconsin - Stout, Menomonie, USA
Mr J. Salvador SANTIAGO, Instituto de Acoustica, Madrid, Spain, President of the Jury

The criteria for the decision were :

- Scientific content
- Clarity of presentation
- Aesthetic quality

90 posters were examined by the jury

The results are :

Special mention award from the President for poster number 31 :
The alternative mechanism of infrasound effect on organism
prepared by :
Boris FRAIMAN, Andrej VORONIN, Elisabet FRAIMAN, Medical Institute, Voronezh, Russia

Third place award for poster number 126 :
A pilot study assessing long term effects on people exposed to low frequency noise in their homes
prepared by :
Kerstin PERSSON, Ragnar RYLANDER, University of Gothenburg, Sweden

Second place award for poster number 107 :
The relation between different noise descriptors for road traffic noise and the extent of annoyance
prepared by :
Martin BJORKMAN, Ragnar RYLANDER, University of Gothenburg, Sweden

Finally, the prize for the best poster has been awarded to poster number 109 :
Cross-cultural comparison of community response to road traffic noise in Japan and Thailand
prepared by :
Wut DANKITTIKUL, Kiyoto IZUMI, Kazutaka KUROSAWA, Muroran Institute of Technology, Takashi YANO, Kumamoto University, and Toshio YAMASHITA, Ariake National College of Technology

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